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A DECISION SUPPORT SYSTEM FOR REAL-TIME SNOW AND ICE CONTROL

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A Decision Support System for Real-Time Snow and Ice Control

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16. Abstract

Effective real-time snow and ice control operations require a timely initial call-out. A timely initial call-out is one that mobilizes the workforce slightly prior to the onset of hazardous road conditions. In order to estimate the onset of hazardous road conditions, the snow and ice control decision makers use available physical and meteorological information. New technologies are developed that could provide better information, thereby improving the ability to make timely initial call-outs. A systematic methodology for evaluating the benefit of additional information used in snow and ice control initiation is presented. The proposed methodology compares reduction in the direct and indirect costs of the call-out, attributable to the new information, to the cost of acquiring the information source. The methodology is implemented to evaluate road weather information systems for the Indiana Department of Transportation.

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CHAPTER 1: INTRODUCTION

1.1 The Problem

In North America, an estimated 2 billion dollars annually is spent on snow and ice control operations (Kelley, 1993). This estimated expenditure is based on expenses for materials, equipment and labor. Given the magnitude of this expenditure, if even small improvements in the management and efficiency of the operation can be achieved, the resulting cost savings can be enormous.

Snow and ice control is a complex problem that is typically addressed at multiple levels (Wright, 1993):

Level 1 - Network Partitioning: Assign roadway segments to service depots.

Level 2 - Route Design: Determine service routes to cover the roadway segments assigned to a given depot.

Level 3 - Resource Allocation: Assign resources, including personnel, to depots as needed.

Level 4 - Real-time Management: Manage snow and ice control operations for a given event in real-time .

Improvements at any level in this topology will help improve overall efficiency of the operation. Efficiency at any level of the operation is related to the quality of the solution at any preceding level.

The fourth level, real-time snow and ice control operations, is the domain of this research. Effective real-time snow and ice control operation involves timely initiation of the operation and efficient management of resources. The usual real-time snow and ice control policy is to maintain, or restore as quickly as possible, bare pavement. The objective of the service provider, usually the public department of transportation, is to meet the policy goal as cost effectively as possible.

In order to achieve this objective, snow and ice control decision makers must decide how to best use the resources under their control. These decisions necessitate addressing question such as:

1. When should the operation be started?
2. How many people should be called out?
3. What chemicals and/or abrasives should be used for the given storm characteristics?
4. Should there be a plan for an additional shift?

The most significant component of real-time snow and ice control operations management will be shown to be the timing of the initial call-out.

1.2 Background

Indiana's Department of Transportation (INDOT), like most other states, is administratively divided into districts. INDOT employs six districts, each one further sub-divided into a set of sub-districts, as shown in Figure 1.1. Each named, shaded region is a district and each delineated region inside a district is a sub-district. Each sub-district is partitioned into three or four units. Indiana currently has 37 sub-districts with 118 units or service depots.

The overall snow and ice control operations management hierarchy of the Indiana Department of Transportation can be seen in Figure 1.2. The head of operations is in charge of snow and ice control operations for the entire department. District managers are responsible for operations in their district. Many of the operational rules are set at the district level. Each district specifies its own rules for personnel accountability. The operations engineer orders and purchases the chemicals for the district. Interaction between the district and sub-district is the responsibility of the sub-district manager. Sub-district managers are responsible for snow and ice control in their district and generally order any abrasives the sub-district requires. However, sub-district managers do not get paid for any overtime hours. Therefore, the actual management of snow and ice control is usually delegated to the sub-district operations foreman. Sub-district operations foremen initiate snow and ice control call-outs by contacting unit foremen within their sub-district who in turn call drivers and appropriate support personnel.

The analysis in this research takes place at the level of the sub-district operations foremen because that is where the snow and ice control call-out decisions are made. Focusing the analysis at this level requires addressing a wide variety of decision-making styles and preferences. Each sub-district operations foreman may use information differently in their decision process. Sub-districts may have different resource constraints. Network characteristics of the sub-districts can also vary.

1.3 Scope of this Research

Originally, the goal of this research was to provide a decision support environment for managing real-time snow and ice control operations in Indiana. Inputs to the envisioned system would include weather forecasts, personnel work status, time-of-day, day-of-week, and resource levels. The system outputs would include recommendations about the most cost effective strategy to employ for the impending storm event. After initial interviews with Indiana Department of Transportation (INDOT) maintenance personnel, it became obvious that efficient real-time operation was almost totally dependent on an effective call-out decision. An effective call-out helps minimize excess resource usage. Limiting early call-outs decreases labor and equipment costs incurred by providing service when it is not necessary. Avoiding late call-outs reduces the material requirements for a storm and provides safer roads to the network user.

Identification of the optimal, or target, call-out time is hypothesized to result from the use of physical and meteorological data in a systematic fashion. Several new weather technologies have been developed over the past decade, which might be used to enhance the efficiency of call-outs. A methodology for evaluating technologies that could improve the call-out became the focus of this research.

This research is presented in four parts. The first, Chapter 2, is a review of weather technologies used in determining the call-out and a review of other work conducted in this area. Chapters 3 and 4, respectively, suggest and implement a

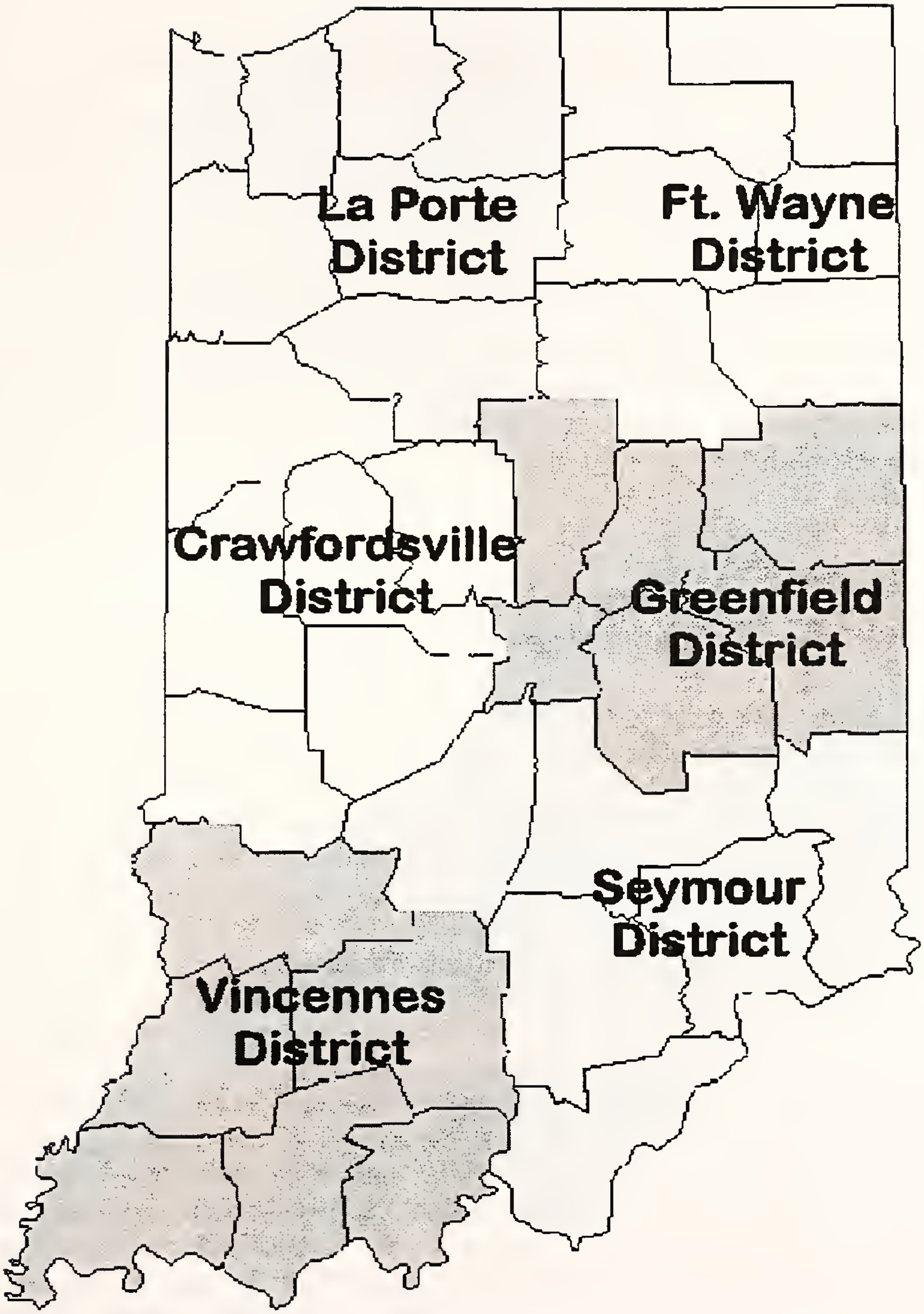

Figure 1.1: INDOT Administrative Break Down

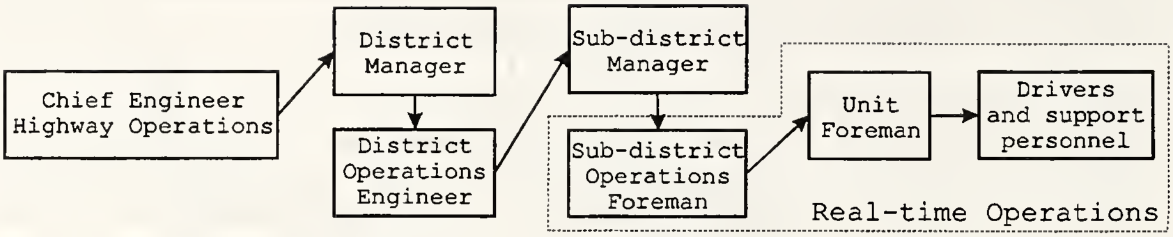

Figure 1.2: INDOT Snow and Ice Control Operations Management Hierarchy

methodology for evaluating benefits, in relation to costs, of adopting a new weather information technology. Lastly, Chapter 5 discusses the results of a methodology implementation. Chapter 5 also presents a critique of the methodology and recommends directions for future analysis.

CHAPTER 2: EFFICIENT INITIATION OF WINTER MAINTENANCE

An efficient winter call-out is achieved when the work force is mobilized at precisely the correct time; neither too early nor too late. Mobilizing the workforce too early results in expenses being incurred for labor and equipment that are not necessary. An additional concern of early mobilization is that consuming scarce labor resources when they are unnecessary may result in labor shortages later in the storm. Late mobilization can result in increased material usage as well as increased costs and risks for the network user. In general, call-outs are left to the discretion of regional operations foremen.

This chapter has three sections. First, the costs associated with ill-timed call-outs are examined in greater depth. This is followed by a section that examines both current and new weather information sources and technologies that are available to the snow and ice control decision maker. Lastly, a discussion of methods for comparing and evaluating investments is presented.

2.1 The Costs of Ill-timed Call-outs

There are a variety of costs associated with inefficient initiation of snow and ice control operations, that can be broken down into two categories, direct costs and indirect costs. Direct costs are those incurred by the snow and ice control provider, usually the public department of transportation. These include increased material costs, increased labor costs, increased equipment costs, and increased stress on the decision maker. Indirect costs of inefficient winter maintenance initiation are incurred by users of the road network and the public. Including increased accidents, increased travel time, increased fuel consumption, increased environmental impact, and decrease in public perception of the quality of management within the department of transportation.

Direct cost increases can result from making call-outs too early or too late. Calling out the workforce too early results in increased labor and equipment costs. Labor and equipment are being used even though there is not yet a need for snow and ice control. Material application is generally not increased in early call-outs. Conversely, when the call-out is too late the cost for equipment and labor decrease slightly because the workforce is mobilized later. However, late call-outs increase material usage substantially because the moisture on the roads has often already begun to freeze. Once the ice has bonded to the pavement it is difficult to manage, and may have to be removed with chemicals, a process called de-icing. If the call-out is made on time, chemicals can react before the ice bond is formed. This is termed anti-icing and requires 30-75% less chemical treatment (Kelley, 1993). Direct costs associated with early call-outs could be quantified by determining the hourly costs for labor and equipment and multiplying it by how early the call-out was made. Late call-out direct costs could be calculated by determining the degree to which the material use increases in relation to how late the call-out is made.

Indirect costs of an ill-timed call-out are generally a function of poor road conditions. If the call-out is late, the plowing and material application meant to minimize the effect of winter weather is delayed. This results in the network user being exposed to hazardous road conditions longer. The costs associated with this increased exposure to hazardous road conditions are difficult to quantify. One recent attempt to quantify the indirect costs of operations is particularly relevant for this research. Hanbali (1994) compared the cost of a bare pavement snow removal policy to the benefits attained by the network users. A bare pavement snow removal policy attempts to maintain, or restore as quickly as possible, bare pavement during winter weather conditions. The benefits included in his analysis were accident reduction, decreased travel time, and decreased fuel consumption.

The Hanbali accident study was conducted in three states, Illinois, Wisconsin, and New York. The study consisted of two-lane highway sections totaling 1,600 lane-km and multi-lane divided freeway sections totaling 400 lane-km. The time, severity, location and traffic density associated with the accidents were recorded and related to the time of the last material application prior to establishment of bare pavement. The material application time was called the zero hour. Accidents occurring 12 hours before the zero hour as well as the 12 hours after the zero hour were considered. Hanbali was then able to establish accident rates and cost rates for the elapsed time before establishing bare pavement as well as the elapsed time after establishing bare pavement. The reduction in accident rates were found to be statistically significant in an earlier paper (Hanbali, 1992). The accident rate reductions were reported for injury accidents and property damage only (PDO) accidents per million vehicle kilometer traveled (acc/MVKT). There were no fatalities on the test sections, so a fatality accident reduction factor was not generated.

The accident rate reductions for injury and property damage only accidents were used to calculate accident benefits derived from winter snow and ice control. These accident rates were multiplied by the Federal Highway Administration (FHWA) accident cost estimates for the respective accident types. The result of these calculations was a estimate of the accident benefit in dollars per MVKT.

Hanbali also considered how fuel consumption was affected by snow and ice control. His work was based extensively on the work done by Claffey (1976). Claffey created curves representing fuel consumption vs. travel speed for various winter road conditions. Hanbali used these curves to determine the increased fuel consumption in liters per vehicle kilometer traveled (l/VKT) based on average normal vehicle speeds for two-lane highways and four-lane freeways. This consumption increase, multiplied by the cost per liter, yielded a fuel consumption benefit in dollars per VKT.

The final benefit Hanbali reported was a travel time benefit. The reductions in travel speed for vehicles traveling on snow and ice conditions were documented in a previous study (McBride et al. 1977). Hanbali determined a normal travel speed and then used the McBride study (1977) to estimate the snow and ice travel speed. Hanbali used the change in travel speed to determine the delay per vehicle kilometer traveled (hr/VKT). Combining this delay with a previously reported time cost per vehicle hour (AAHSTO, 1977), he was able to report a travel time benefit in dollars per VKT.

Hanbali's calculated benefits were a related to the volume of traffic over the roadway. During the course of the research Hanbali also found traffic volumes to decrease during winter snow conditions (Hanbali and Kuemmel, 1993). In order to calculate accurately the benefits of a bare pavement removal policy, Hanbali used the reduced traffic volumes with the cost savings determinations.

There are direct and indirect costs associated with an ill-timed call-out. Hanbali (1994) has shown the ability to quantify certain indirect benefits. Quantifying the direct benefits is a matter of determining how resource usage changes . If the information given to the decision maker improves and results in a better call-out, the benefits are quantifiable.

Over the past decade, several technologies have been developed that might serve to improve the timing of winter call-outs. The following section discusses the weather information sources available to a person responsible for initiating snow and ice control call-outs.

2.2 Technologies for Understanding Weather

Weather information is of great importance to winter personnel. Sources of this information range from traditional television and radio reports and forecasts, to commercial meteorological service providers. New technologies are being developed using advanced satellite and telecommunications technologies, and will continue to evolve in the future. The central product of this research is a systematic methodology for evaluating the benefits and costs of employing these technologies. To that end, it is important to understand the strength and weaknesses of existing technologies; those that will be used to demonstrate this methodology. A review of several of these technologies is presented below.

2.2.1 Television and Radio Forecasts

Public television and radio weather are a part of everyday life. This type of information assimilation is the main source of weather information for most people. They give general information about the anticipated weather. Including an estimated daily high and low temperature as well as type and amount of precipitation expected. This information is presented and updated a few times a day.

In addition, television weather forecasts usually contain some satellite imagery that is of benefit to winter maintenance decision makers. Satellite imagery, although on a large scale, can show the direction of a storm front. Knowing the approach direction of storm aids the decision maker in two main ways. First, an individual can be called in to patrol the area and notify the decision maker when adverse conditions begin. Another advantage of knowing the path of the storm is the ability to contact areas that the storm will impact prior to the current area. This contact can provide information that allows decision makers to react in more timely fashion to the incoming storm. One very desirable attribute of television and radio weather forecasts is that they are virtually free. An exception to this is the cable weather channel.

The weather channel is provided by most cable television networks. Although access to the weather channel has a small fee it has several advantages over public television forecasts. First, it provides weather forecasts and information 24 hours a day with updates every hour, unlike public television weather forecasts that are usually parts of the scheduled news reports. Second, the weather channel uses a great deal of satellite imagery with its weather forecasts. Snow and ice control personnel can use these images to track the storm system and try to anticipate its arrival and departure. Thirdly, the weather channel includes alphanumeric weather information with the regional weather updates.

Wabash sub-district personnel pay for the weather channel with their own money to have full motion radar (Brock, 1994). While the added benefits of the weather channel are significant, television and radio forecasts do not include precise start of stop times of precipitation, nor do they inform about regional variations in expected weather. Unfortunately, for snow and ice personnel, these pieces of information as well as others are crucial for winter maintenance. “Weather information provided by the media tend to be more cute than they are accurate: a sun disk hiding behind clouds, raindrops scattered here and there, snow crystals covering half a state, and maximum and minimum temperatures each with a ten-degree margin of error”(Reiter and Teixeira, 1993). Another shortcoming of this information source is that it is not interactive. The information is presented to the user. The user has no input on what or how information is presented.

Television and radio weather forecasts aid snow and ice personnel by heightening their awareness of potential hazardous weather conditions. With heightened awareness, snow and ice control personnel can look toward other sources for more specific information.

2.2.2 Value-Added Weather Information Providers

Value added weather information is a commonly used source of weather information in snow and ice control. In the early 1980’s the National Weather Service (NWS) began delivering bulk weather data to the weather information industry through a set of medium speed data circuits. The weather information industry then provides either these raw data or value-added products and services to the end user. (Glickman, 1990) Even though the type and quantity of information have changed greatly over more than a decade, the concept has not. The private sector receives data from the NWS, manipulates it, and sells the various value-added information to almost all end-users of meteorological data.

There are two distinct types of value-added weather services:

1. Trigger: The service provider notifies the subscriber of impending weather and supplies the suspected attributes of the storm.
2. Database: The user can query a weather information database for certain types of information that are pertinent to the decisions at hand.

“Trigger” style weather information is usually given orally over the radio or sent to a fax machine and is geared more for snow and ice control personnel than public weather information sources. Suspected start and stop times are provided as well as the type and quantity of precipitation expected. Additional storm attributes such as wind speed and direction are also often given. The problem with this information is the degree of accuracy of the forecasts. Because of the nature of this type of service, “trigger” type services tend to be very conservative. The cost of these services is moderate and usually predetermined for a specific period.

Value-added weather information databases hold many types of meteorological information. Weather database services exist for interactive, on demand use. Most commonly used by snow and ice control personnel are the relatively current regional satellite and radar images. These images can be linked to show the motion of the impending storm event. Alpha-numeric storm descriptions are also available that describe the storm specifics like expected start and stop times, type and quantity of precipitation, and wind speed and directions. This type of information is usually obtained via a computer through a dial up connection. There is an initial fee for access to the system, and subsequent use-based charges. The overall cost is modest as long as some prudence is shown on the part of the user.

2.2.3 Road Weather Information Systems

A road weather information system (RWIS) is a network of remote processing units (RPU) interconnected through one or more central processing units (CPU). Road weather information systems are unique in comparison to other types of weather information because they supply both pavement and weather information. In addition, RWIS provides both actual and forecasted information.

Remote processing units usually consist of four road sensors, one sub-surface probe, a weather station and a remote computer. The general configuration of a Remote processing unit can be seen in Figure 2.1. The remote processing unit collects the remote site information and transmits it to the central processing unit. The central processing unit can then provide the following information to the user (Balgowan 1987):

1. Date
2. Time
3. Surface Temperature
4. Air Temperature
5. Dew Point Temperature
6. Relative Humidity
7. Wind Direction
8. Wind Speed
9. Sensor Number
10. Physical Location
11. Roadway Status (e.g. dry, wet, snow/ice alert, chemically wet)
12. Chemical Factor (indication of chemical presence, such as salt, in the moisture on the surface)

This information can be updated as frequently as every 15 seconds, providing virtually real-time information to the snow and ice control decision maker about any remote site location. A general RWIS configuration is shown in Figure 2.1.

An important component of the RWIS technology is the site specific pavement forecast. It is more important to forecast pavement temperature than air temperature because ice formation is dependent on the temperature of the pavement surface (Kelley et al. 1987). The difference between pavement and air temperature can easily exceed 7°C (Kelley, 1993). The surface and sub-surface sensors in conjunction with meteorological

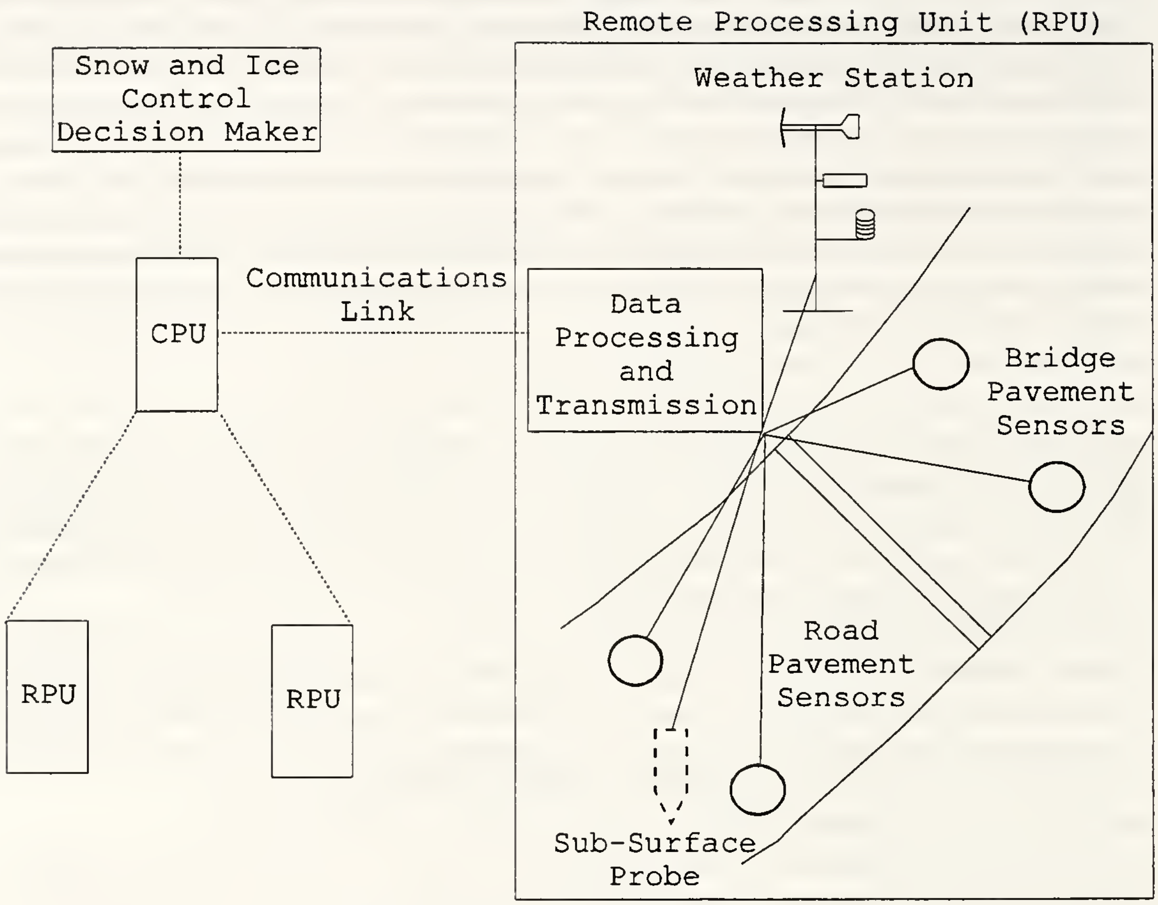

Figure 2.1: General RWIS Configuration

data provide information that enable accurate 12 and 24 hour pavement forecasts. Research has shown that pavement temperature can be forecast within 1° C (2° F) 90 percent of the time and the site specific forecasts are better than 80 percent accurate (Boselly, 1993). This accuracy would allow snow and ice control decision makers to plan their call-outs using the site specific pavement forecasts. RWIS technology has shown benefits in several implementations around the United States as well as throughout Europe. As of July 1992, 12 European countries have installed 2,533 remote processing units (Han and Lukanen, 1994). Much of the RWIS development in Europe is a result of government support (Boselly, 1992). Several states have, or are planning, statewide implementation of RWIS technology including, Illinois, Iowa, Kansas, Minnesota; New Jersey, Virginia, and Wisconsin.

RWIS technology provides pavement and weather information that is pertinent to the snow and ice control call-out decisions. Access to the real-time pavement and weather information can be used to track the storm as it approaches. The site specific forecasts give accurate information that can be used to plan regional call-outs. The major disadvantage of RWIS is the large initial capital investment.

2.2.4 Summary

It is important to realize that no one source provides all of the weather information required to efficiently manage snow and ice control operations. All of the above weather information technologies present some form of prediction of impending surface weather conditions. RWIS appears to be the most complete technology for aiding the snow and ice control decision maker. RWIS is unique in that it provides information, both actual and forecasted, about the condition of the road surface.

Costs of these technologies can be quantified. Using analytical techniques and the experience of snow and ice control personnel the benefits derived from technologies can be estimated. The following section presents methodologies for comparing the costs and benefits in order to determine if acquisition of technology is a sound investment decision.

2.3 Comparing Investment Alternatives

Several frameworks for evaluating the desirability of investment decisions are commonly used by engineering managers including minimum attractive rate of return (MARR) and benefit-cost ratio (BCR) (Thuesen and Fabrycky, 1993). The minimum attractive rate of return (MARR) is used to evaluate a set of mutually exclusive investment alternatives. The alternative not to invest is termed “do nothing”. The “do nothing” alternative assumes that all available funds are invested at the MARR. In comparing one investment to another, first determine the cash flow representing the difference between the investment alternative cash flows. The incremental investment is considered to be desirable if it yields a return that exceeds the MARR (Thuesen and Fabrycky, 1993). The difficulty with this method is determining what MARR should be used. One guideline suggests the MARR should be set no lower than the rate of a bank savings account because that investment option is always available.

A popular method for deciding upon the economic justification of a public project is to compute the benefit-cost ratio (Thuesen and Fabrycky, 1993). The benefit-cost ratio can be expressed as the following:

$$BC(i) = \frac{B}{I + C} \qquad 2.1$$

Where:

B = net equivalent benefits to the user

I = equivalent capital invested by the sponsor

C = net equivalent annual costs to the sponsor

$BC(i)$ = benefits cost ratio with equivalent amounts computed using i

The project is justified if the BC(i) value is greater than one. For a more detailed description of various means for economic comparisons the reader is directed to Thuesen and Fabrycky (1993).

The following chapter presents a benefit-cost assessment methodology for valuing weather information to determine if the cost of acquiring a new weather information technology will be recovered in the benefits gained by using the technology. The method is applied to the INDOT in Chapter 4. Results and discussion of the implementation are presented in Chapter 5.

CHAPTER 3: A METHODOLOGY FOR EVALUATING THE BENEFIT OF ADDITIONAL INFORMATION IN SNOW AND ICE CONTROL MOBILIZATION

The following chapter presents a methodology for evaluating the benefits of additional information in snow and ice control mobilization. First, a procedure for evaluating benefits derived from a new weather information source is presented. This is followed by a methodology for determining costs of implementing the new weather information source. The chapter concludes with a method for ascertaining the desirability of new weather information by comparing benefits to costs.

3.1 Evaluation Methodology

The evaluation methodology incorporates three components: 1) determining the benefits of new weather information, 2) determining the costs of implementing and maintaining the new weather information source, and 3) comparing benefits and costs. A flow chart of the evaluation methodology can be seen in Figure 3.1.

Today, organizations are expected to operate as efficiently as possible. In order to meet this expectation, it is important to develop methodologies for evaluating technologies that could be used to make an operation more efficient. Failure to adopt beneficial technologies results in lost potential improvements. Likewise, adopting a technology that is not more beneficial than its cost wastes resources thereby decreasing the operational efficiency. Developing a methodology for evaluating the desirability of new weather information technologies allows the snow and ice control provider to adopt only those technologies that would have an overall net benefit.

3.1.1 Methodology for Determining Benefits

The methodology for determining benefits of a new weather information technology is presented in six steps. Step 1, identify benefits and benefit types; Step 2, determine a call-out cost profile; Step 3, compare decisions using old information to decisions using new weather information; Step 4, quantify direct costs; Step 5, quantify indirect costs; Step 6, expand costs to statewide level. These steps can be seen in the benefit determination box of Figure 3.1.

Step 1: Identify Benefits and Benefit Types

The first step in evaluating the benefits will be to determine what benefits are going to be included in the analysis. Benefits will be broken down into two types: 1) direct benefits, the effect of limiting the direct costs, and 2) indirect benefits, the reduction of the indirect costs. Direct benefits are realized by the snow and ice control provider, usually the public Department of Transportation (DOT). Indirect benefits are realized by network users and society. It is important to make the distinction between benefit types. A project needs to be feasible within the budget of the department of transportation. Direct benefits

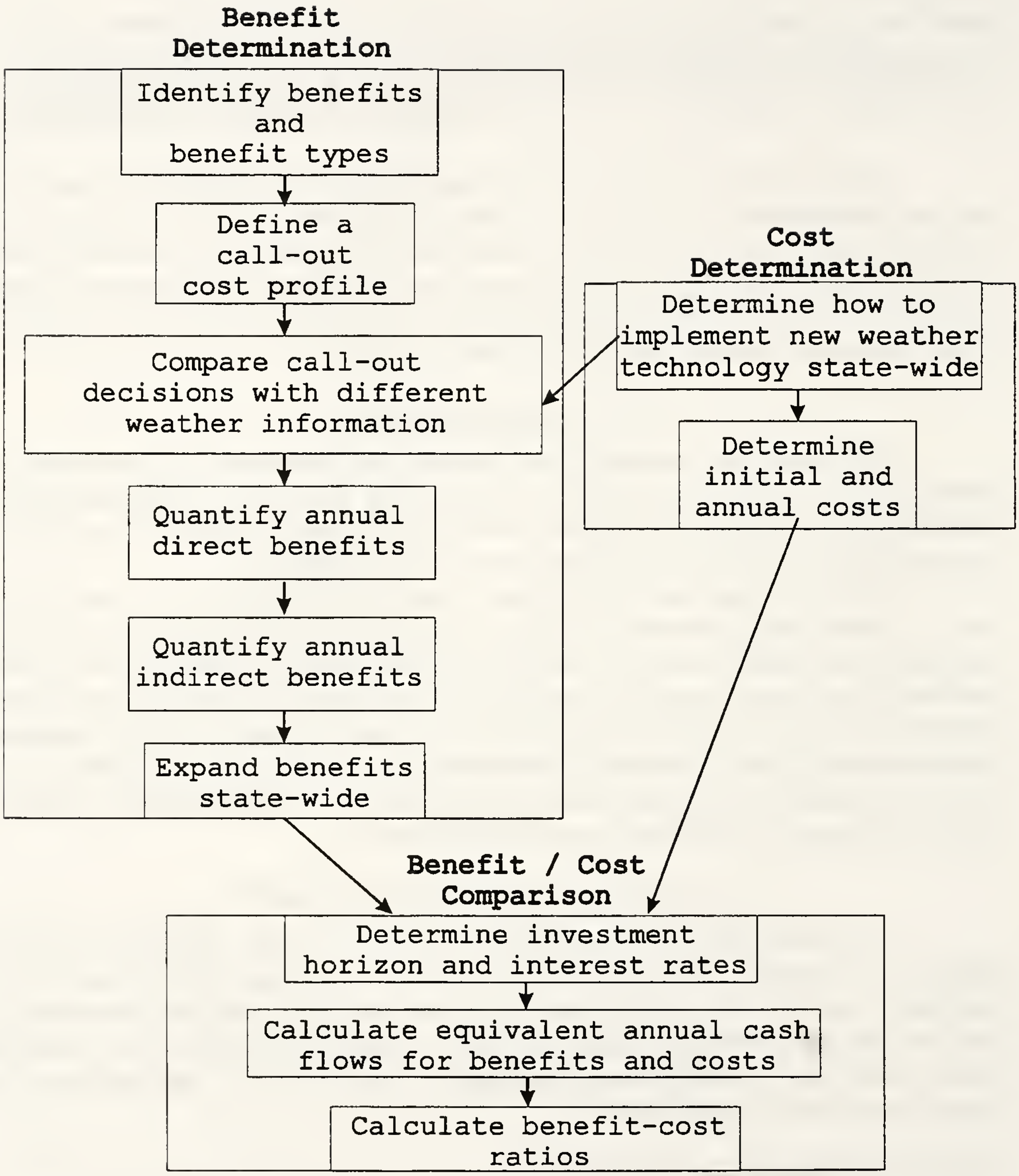

Figure 3.1: Methodology Flow Chart

will be a source of funding for the project. However, indirect benefits are realized by network users and society and will not be available to fund the project. The decision to adopt the project may then only relate to the comparison of direct benefits to total costs.

After distinguishing between the types of benefits, each benefit will be categorized as tangible or intangible. A benefit is deemed tangible if it is possible to associate a reasonable dollar figure with it. Conversely an intangible benefit is either impossible or impractical to quantify monetarily (Hanbali, 1994). Only tangible benefits will be included in this analysis because all of the comparison inputs are required to be monetary. How intangible benefits are affected by new weather information will be discussed. Since no monetary measure of this benefit is plausible, the discussion of the effects will be relative to the old information. The following section is a methodology for determining a call-out cost profile.

Step 2: Define a Call-out Cost Profile

The second step in determining the benefits derived from new weather information will be to define a call-out cost profile. The call-out cost profile will show the relationship between call-out timing and the cost of the operation. A basis of comparison must be determined to relate call-out decisions using old information to call-out decisions using new information. The call-out cost profile will be developed by examining how the costs change in relation to call-out timing for the basis of comparison.

Determining the basis for comparison is difficult because winter weather can vary greatly from year to year and from region to region. The basis for comparison used in this methodology will be a hypothesized typical call-out. Unfortunately, INDOT does not maintain records that could be used to determine a typical call-out accurately. An alternate approach will be to have the concept of a typical call-out developed using the expertise of a group of representative snow and ice control decision makers. The snow and ice control decision makers in this case are the sub-district operations foremen. In order to account for some of the regional variability of weather and different decision making styles, a typical call-out will be defined for each sub-district.

Determining a typical call-out necessitates trying to estimate material use, labor and equipment requirements, average storm duration, and the distribution of material, labor, and equipment costs over the estimated storm duration. These estimates can be divided into typical storm costs and typical storm characteristics. Typical storm costs will include labor, equipment and material costs. Typical storm characteristics will include storm duration and resource distribution. Resource distribution will describe how the typical costs would be distributed over the duration of a typical storm. The representative sub-district operations foremen will make these estimations based on their experience. Unfortunately, there is no way to document the accuracy of the typical call-out determination. Initially, the typical call-out will be developed assuming the call-out was made at precisely the optimum, or target, time.

In reality, the call-out for a storm can either be exactly correct, early or late. Recall from Section 2.1 that costs increase for both early and late call-outs. The general relationship between the timing of the call-out and the resulting costs associated with call-out can be seen in Figure 3.2. Sub-district operations foremen will be asked to describe how their call-outs vary from the target call-out. Their responses will be used to separate the cost profile into a series of deviation categories. The following section presents a methodology for comparing the decisions made with old weather information to decisions made with new weather information using the deviations categories.

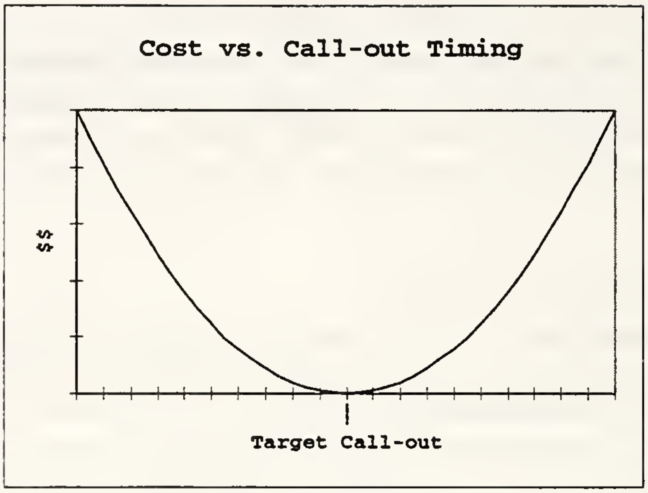

Figure 3.2: Cost vs. Call-out Timing

Step 3: Compare Call-out Decisions with Different Weather Information

The third step is to compare the decisions made with old weather information to the decisions made with new weather information. The sub-district operations foremen will be asked to suggest how many times during an average year they make this typical call-out. They will then be asked how many of those decisions would be on target and how many would fall in each deviation category.

Sub-district operation foremen will then be shown the new weather information source. This will include the access to the information, the frequency with which the information is updated, as well as the documented accuracy of the information. Given an understanding of the new weather technology, they will be asked to estimate how many of their decisions would be on target and how many would fall in each deviation category. The frequency change in call-out decisions from old information to new information for each deviation category will be used to quantify both direct and indirect benefits. The next section presents a methodology for quantifying annual direct benefits.

Step 4: Quantify Annual Direct Benefits

The fourth step will be to quantify the direct benefits, the effects of reducing the direct costs. First, the increase in direct costs for each deviation category will be calculated. The sub-district operations foremen will be asked to describe how the costs of the operation change for each deviation category. The increased cost for each of the deviation category can be symbolically represented the following way.

$$\Delta Cost_{i,j} = C_{i,j} - C_{opt,j} \qquad 3.1$$

where :

$$i = \text{devation type}$$
$$j = \text{sub - district number}$$
$$C_{i,j} = \text{cost of operation for call - out deviation type } i \text{ for sub - district } j$$
$$C_{opt,j} = \text{total cost of operation with an optimal call - out at sub - district } j$$
$$\Delta Cost_{i,j} = \text{increased cost for call - out deviation type } i \text{ for sub - district } j$$

The frequency change in deviation categories, determined in the previous step, and their respective increased cost are the inputs for determining direct benefits. The annual direct benefits, for each sub-district, can be estimated using the following equation.

$$DBenefit_j = \sum_{i=1}^{n} \Delta Cost_{i,j} * \Delta F_{i,j} \qquad 3.2$$

where:

$$i = \text{devation type}$$
$$j = \text{sub - district number}$$
$$n = \text{number of deviation types}$$
$$\Delta Cost_{i,j} = \text{increased cost for call - out deviation type } i$$
$$\Delta F_{i,j} = \text{change in frequency of deviation type } i$$
$$DBenefit_j = \text{direct benefit for sub - district } j$$

The following section is a methodology for quantifying the annual indirect benefits.

Step 5: Quantify Annual Indirect Benefits

Step five of the methodology is to quantify indirect benefits, the effect of reducing the indirect costs. These benefits will be calculated by determining the volume of traffic affected by improving call-out decisions with new weather information. This will be determined in a manner very similar to the direct benefits quantification. The difference will be, instead of determining the cost increase for each deviation category, the sub-district operations foremen will be asked to estimate the increase in the amount of time the roads conditions were hazardous due to snow and ice covered pavement. The same change in deviation category frequencies apply from the calculation of the direct benefits. Therefore, the total time hazardous road conditions are avoided, by using the new weather information, can be characterized by the following equation.

$$TSave_j = \sum_{i=1}^{n} \Delta T_{i,j} * \Delta F_{i,j} \qquad 3.3$$

where :

i = the devation type

j = the sub - district number

n = the number of deviation types

$\Delta T_{i,j}$ = the increased hazard time for deviation type i for sub - distict j

$\Delta F_{i,j}$ = the change in frequency of deviation type i

$TSave_j$ = the total time of hazardous road conditions avoided for sub - district j

The total time that hazardous road conditions are avoided will be used to determine the traffic volume not exposed to the hazardous road conditions. Annual average traffic volumes will be calculated for two lane highways and four lane highways. The calculated numbers will be adjusted to account for winter weather volume reduction. The time saved will be multiplied by the adjusted daily volume to determine the volume of traffic affected by using the new weather information.

Recall from Chapter 2, Section 2.1, that Hanbali (1994) calculated indirect benefit factors for snow removal in terms of vehicle kilometers traveled (VKT). Using this approach, the indirect benefit factors per vehicle kilometer traveled will be determined for the reduction in accidents, travel time, and fuel consumption. Annual Indirect benefits will be calculated as the product of the indirect benefit factors and the volume of traffic affected by decreasing the amount of time hazardous road conditions existed. The following section presents a methodology for expanding the annual benefits from a representative level to a statewide level.

Step 6: Expand Annual Benefits Statewide

In order to compare the costs of a statewide implementation of a new weather technology to the benefits derived from it use, it will be necessary to estimate, using the representative sub-districts, the benefits for the entire state. Statewide benefit expansion can be done in two ways. First, one can assume that the benefits derived from the new technology would be equal in all sub-districts regardless of location or size. This uniform benefit approach would take the average of the benefits for the representative sub-districts and multiply it by the total number of sub-districts in the state to obtain the statewide benefits. Alternatively, the benefits derived from the new technology can be assumed to be proportional to the amount of money each sub-district spends on snow and ice control. The proportional benefit approach would have a benefit factor equal to the total state expenditure for snow and ice control divided by the total expenditure for the representative sub-districts. Both benefit expansion methods will be used in this research since it is not conclusive which of the methods would be most appropriate. The following section will present the methodology for calculating the costs of a statewide implementation of a new weather technology.

3.2.2 Methodology for Quantifying Costs

The methodology for quantifying the costs of implementing a new weather technology has two steps. First, determine how to implement the system on a statewide basis. Second, determine the costs for the suggested implementation and categorize the costs as initial and annual. The following section presents a methodology for determining how to implement a new weather information source.

Step 1: Determine Statewide Implementation

The first step in quantifying the costs will be to determine how to implement the new weather information technology statewide. In order to understand how to implement the new weather information technology two sources of information will be used. First, other states that have already implemented the new weather information technology will be studied to aid in selecting the correct configuration. Second, a vendor of the technology will be asked how the new weather technology should be implemented. Information gathered from both sources will be used in conjunction with information concerning the state's current infrastructure to determine the desired implementation. The following section presents a methodology for determining the initial and annual costs of the proposed implementation.

Step 2: Determine Initial and Annual Costs

Once the best way to embrace the technology is decided, the cost of each component will be determined. The costs will be classified as an initial cost or an annual operational cost. This will be done extensively using other states' experiences. Costs for hardware, installation, training, maintenance, and vendor support will be included in the cost generation. The following section presents a methodology for comparing the costs and the benefits to determine if adopting a new weather information is a sound policy decision.

3.2.3 Methodology for Comparison of Costs and Benefits

The methodology for comparing the benefits of a new weather information technology compared to the costs, using a benefit-cost ratio, has three steps. First, the investment horizon and interest rates will be determined. Second, equivalent annual cash flows for the benefits and the costs will be calculated for the investment horizon. Third, the equivalent cash flows will be used to calculate benefits costs ratios for adopting the new weather technology.

Determine the Investment Horizon, Inflation Rate, and Market Interest Rate

A benefit-cost analysis is the process of calculating the ratio of the benefits over the costs. The benefits and costs are usually compared as present values or amortized annuities. In order to calculate either present values or amortized annuities, the investment horizon, inflation rate and market interest rate must be determined. The selected horizon will depend on the organization and the nature of investment required for the project.

Organizations generally use several different horizons to evaluate potential investments. Therefore, the investment horizon used in the analysis will be selected from the investment horizons supplied by state policy personnel. The inflation rate for a proposed project can be speculated from historical price indices. There are several price deflators available, notable are the Consumer Price Index (CPI) and the Producers Price Index (PPI). The CPI is based on the fixed market basket of consumer goods at retail prices. The PPI is an index based on a fixed basket of consumer goods at wholesale prices (Bureau of Labor Statistics, 1995). Inflation rates in this study will be generated using the CPI. There are two main reasons for this selection: 1) the CPI is commonly used to escalate income payments (Lohmann, 1981), and 2) the market basket include relevant items including food, housing, transportation, utilities, and medical expenses. Actual determination of inflation rate will be estimated by determining the average inflation for a period of time equal to the investment horizon prior to the investment. The estimated inflation rate will be used to inflate the annual costs and benefits. After the benefits are inflated, the present value of the resulting cash flow can be calculated using the market interest rate. The market interest rate used to evaluate public project should reflect at least the government's cost to borrow money (Thuesen and Fabrycky, 1993). To this end the market interest rate will be set to the prime rate. The following section presents a methodology for calculating the equivalent annual cash flows for benefits and costs.

Calculate Equivalent Annual Cash Flows For Benefits and Costs

In order to generate the benefit-cost ratios, the benefit and cost equivalent cash flows need to be calculated for the investment horizon. The cost cash flow will have two components, initial and annual. The initial costs will be amortized over the investment horizon using the market interest rate. The calculated annual operational costs and annual benefits will be inflated yearly to account for inflation. The inflated annual cost and benefit cash flows will be transformed into an equivalent annual series using the market interest rate. Amortized initial and equivalent annual costs will be combined into one cost cash flow. The equivalent annual benefits will remain separated into their respective groups, proportional direct benefits, proportional indirect benefits, uniform direct benefits and uniform indirect benefits. The following section presents the method for determining the benefit-cost ratios from the equivalent annual cash flows calculated above.

Calculating the Benefit-Cost Ratios

The resulting annuities can be used with equation 2.3 to calculate the benefit-cost ratios. Three types of benefit-cost ratios will be used, direct benefits to total costs, indirect benefits to total cost, and total benefits to total costs. These three ratios will be calculated for both uniform and proportional benefit expansions. The next chapter implements the methodology presented above regarding the acquisition of road weather information system (RWIS) technology by the Indiana Department of Transportation (INDOT). This is followed by a chapter that discusses the results of the implementation, critiques the methodology, and presents directions for further research.

CHAPTER 4: METHODOLOGY IMPLEMENTATION

The problem methodology presented in Chapter 3 was applied to determine the desirability of acquiring road weather information systems (RWIS) for the Indiana Department of Transportation (INDOT). Quantifying benefits of RWIS technology is the first section of this chapter. This is followed by a section quantifying costs of a statewide implementation of RWIS technology. Chapter Four concludes with a section comparing benefits to costs using a benefit-cost ratio.

4.1 Quantify the Benefits in Indiana

4.1.1 Benefits Included in the Analysis

The result of completing Step 1 was the identification of the following direct and indirect benefits.

Direct Benefits,

Decreased materials usage: Material use is decreased by reducing lateness of call-outs. A late call-out allows moisture to freeze and bond with the pavement. More chemicals are required to break the bond than are required to keep the bond from forming.

Decreased equipment costs: Equipment costs increase if call-outs are made too early. Trucks are being used even though there is not yet need for snow and ice control.

Decreased labor costs: Labor costs also increase if the call-outs are made too early. Personnel are being paid before there is a need for snow and ice control.

Indirect Benefits,

Decreased accidents: Accidents are decreased by reducing the lateness of call-outs. When a call-out is late, the roads are hazardous longer than they would be had the call-out been made at the appropriate time. Hazardous road conditions have been shown to increase accident rates. Decreasing the amount of time there are hazardous road conditions would reduce the number of accidents.

Decreased travel time: The decreased travel time benefit is also a function of reducing the amount of time road conditions are hazardous. The travel speed of a vehicle has been shown to decrease when road conditions are hazardous. Trips take longer to complete when traveling at a decreased speed. Decreasing the amount of time there are hazardous road conditions would reduce the time it takes to reach the desired destination.

Decreased fuel consumption: Again, decreased fuel consumption is a function of reducing the amount of time the road conditions are hazardous. It has been shown that fuel consumption increases when traveling on snow covered pavement. Reducing the amount of time of hazardous road conditions would reduce the time fuel consumption is increased.

The direct benefits named above were selected because the costs associated with them are the main expenses in snow and ice control operations. Indirect benefits included in this analysis were the most commonly used benefits in other similar research (Hanbali, 1994)(Pilli-Sihvola et al., 1992). This previous research provided a framework for determining the value of indirect benefits. Additional potential benefits mentioned earlier that are not included were not possible to quantify accurately for this analysis. These include, stress on the decision maker, public perception of the service provider and environmental impact. Not including these benefits will make the benefit estimation conservative.

4.1.2 Define a Call-out Cost Profile

Typical Storm Costs

Typical storm costs were formulated using the expertise of an advisory group of INDOT sub-district operations foremen. The advisory group was formed by asking each of the four northern district managers to recommend one sub-district operations foreman within their district to assist with the research[1]. This approach was suggested by the head of INDOT operations support (Goode, 1994). The criteria given to the district managers were that the person recommended would be able meet periodically to help define the real-time snow and ice control problem and would also be able to give input on and evaluate any solution procedures. The sub-district foremen involved with the entirety of this research were, Bill Fielding, Carl Kindig, and Joe Olsen from the Cloverdale, Plymouth and Tipton sub-districts, respectively. These sub-districts are shown in Figure 4.1. Each of the sub-district operations foremen in the representative group was asked to estimate the resources they used in a typical call-out: labor, equipment and material. Labor included the number of unit foremen, the number of drivers, the number of support personnel and the sub-district operations foreman. The specific numbers for each labor group are shown in Table 4.1. Column one describes the item being quantified. The second column is the indicated number of the that item used in the sub-district's typical call-out. Column three is the hourly cost for the item and the fourth column is the product of the number of items and the hourly cost. Hourly wages earned by all persons involved were different, therefore the wages were averaged for each labor type. It should be noted that the hourly wages in this analysis were all regular time even though many of the actual storm hours are at a premium wage. The premium wage was not used in this analysis because the INDOT maintenance management computer system that tracks snow and ice control expenses, uses only the regular wages. The number from the maintenance management computer system will be used to possibly validate the typical call-out development and to expand the benefits to a statewide level. As a result of using the regular wage, the direct benefits will be slightly conservative.

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[1] Unfortunately, one of group members left the Indiana Department of Transportation during the course of this research. It was impractical to find a replacement at that juncture so the research was continued with only three sub-district operations foremen.

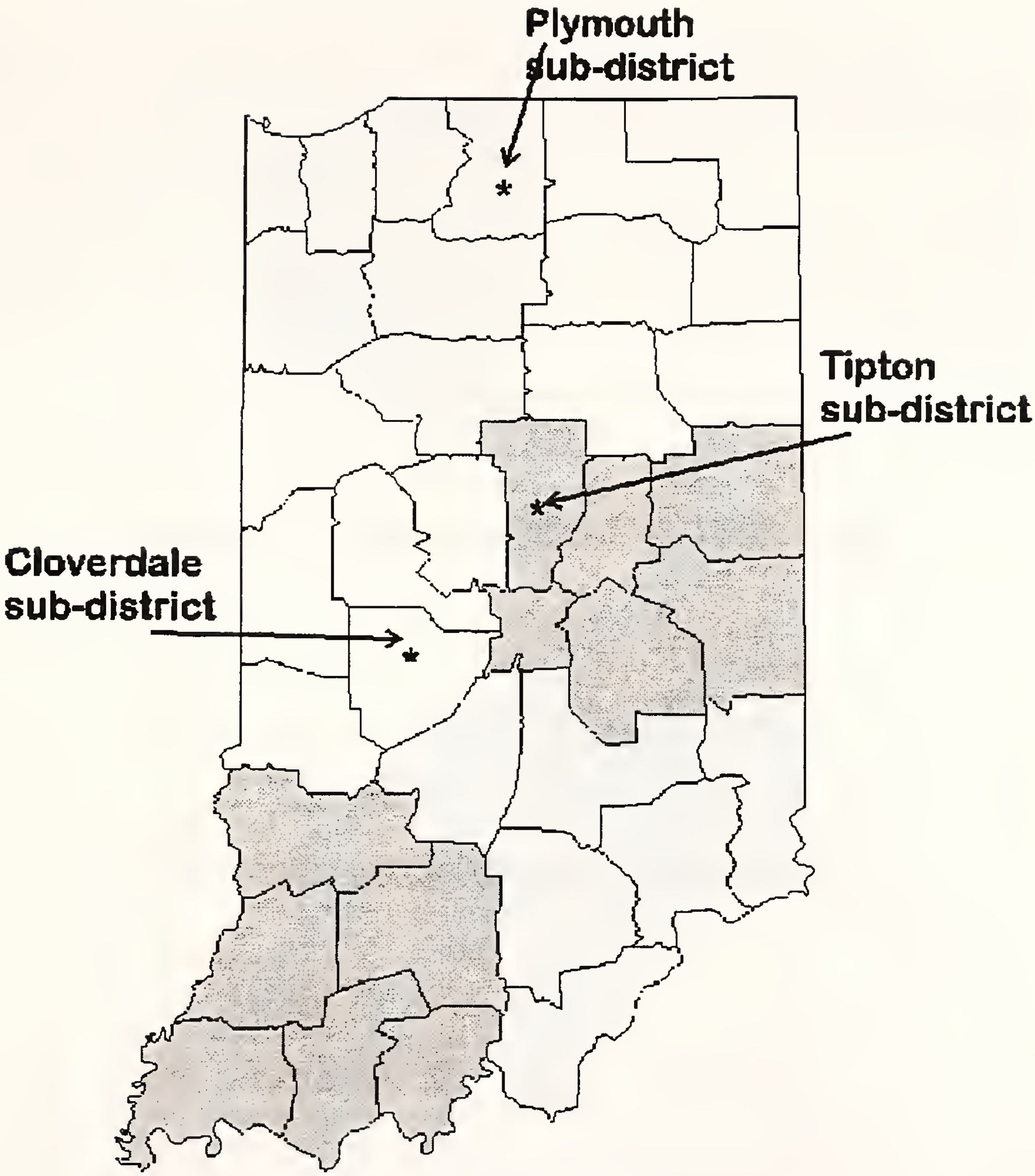


Figure 4.1: Representative Sub-districts

Two types of trucks are used by the sub-districts, single and tandem. The sub-district foremen recorded the number of each type of truck used in their typical call-out. INDOT has previously determined the hourly cost of each type of truck. The equipment component of the typical cost is shown in Table 4.1 by truck type. Costs for labor and equipment were grouped together because their costs per hour are assumed to be constant in relation to call-out timing. The dollar totals for the combination of labor and equipment are shaded for each sub-district in Table 4.1.

The predominant material cost for INDOT is salt although they use sand and calcium chloride under certain conditions. Salt is the only material cost used in this analysis. The number of trucks spreading material was established from the equipment and labor. The hourly cost of material use was estimated by using INDOT policy goal of 250 pounds per lane mile (Field Operations Manual, 1978). That number was multiplied by 17.5 miles, the estimated number of miles a truck applies material to in an hour, to obtain the total material usage per truck per hour. The cost of salt is approximately 33.33 dollars per ton. Converting the units, this calculates to 72.91 dollars per hour per truck. Material costs per hour are shown in Table 4.1 for each sub-district.

Table 4.1: Quantifying Typical Hourly Costs by Resource Type

[1] Item Description		[2] Number	[3] Cost $/hour	[4] Total $
Cloverdale				
Labor				
	Operations foreman	1	14	14
	Unit foremen	3	11	33
	Drivers	26	9	234
	Support personnel	4	9	36
Equipment				
	Single Trucks	18	16.74	301
	Tandem Trucks	8	20.87	167
Labor and equipment total $/hour				785
Material				
	Salt	26	72.91	1,896
Material total $/hour				1,896
Plymouth				
Labor				
	Operations foreman	1	14	14
	Unit foremen	3	11	33
	Drivers	25	9	225
	Support personnel	4	9	36
Equipment				
	Single Trucks	15	16.74	251
	Tandem Trucks	10	20.87	209
Labor and equipment total $/hour				768
Material				
	Salt	25	72.91	1,823
Material total $/hour				1,823
Tipton				
Labor				
	Operations foreman	1	14	14
	Unit foremen	3	11	33
	Drivers	18	9	162
	Support personnel	4	9	36
Equipment				
	Single Trucks	10	16.74	167
	Tandem Trucks	8	20.87	167
Labor and equipment total $/hour				579
Material				
	Salt	18	72.91	1,312
Material total $/hour				1,312

Typical Storm Characteristics

Base storm characteristics were also established using the expertise of the sub-district operations foremen. The sub-district operations foremen indicated there was approximately thirty minutes of labor and equipment time used before any material was applied. This accounted
for preparing the snow removal vehicle and filling the loader with material. The length of the typical storm established for each of the sub-districts was different. Sub-district operations foremen indicated the material use during the typical storm with no error in call-out was constant. The exception to this was the last hour which was usually used for clean up, during which no material is used.

The duration of resource usage is the length of the typical storm as identified by the sub-district operations foremen. The typical storm costs can be plotted over the storm duration resulting in typical storm cost functions. These typical storm cost functions assuming the target call-out are shown in Figure 4.2.

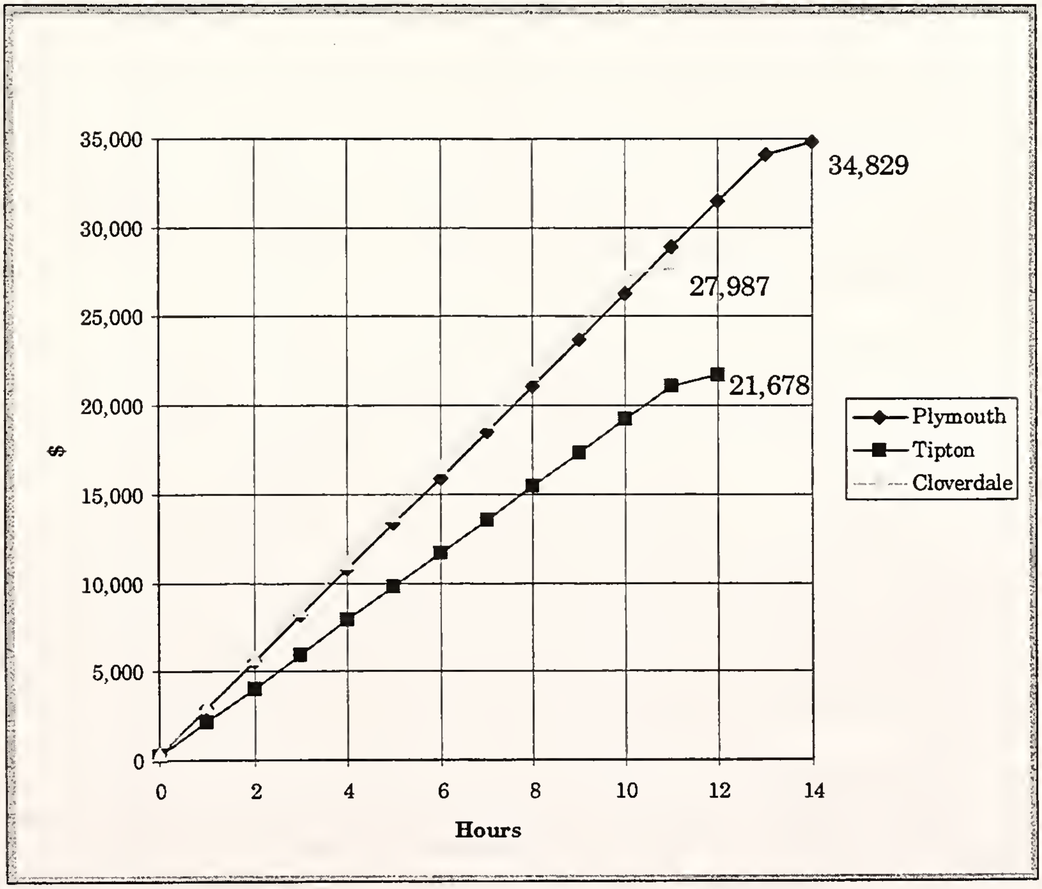


Figure 4.2: Typical Storm Cost Functions by Sub-district

The sub-district operations foremen were asked to suggest how their call-out decisions varied from the target call-out over average year. Four categories of deviation from the target call-out were identified based on the replies of operations foremen, very early, slightly early, slightly late and very late. As mentioned earlier, the costs increase for both early and late call-outs. Deviation categories will be used to categorize the call-out cost profile. The next section presents the results of comparing call-out decisions made with old weather information to call-out decisions made with RWIS information using the identified deviation categories.

4.1.3 Comparing Call-Out Decisions Using Different Weather Information

Sub-district operation foremen were asked to suggest how many times during an average year they make the typical call-out. They were then asked how many of those decisions would be on target and how many would fall in each deviation category during an average year using current weather information. The responses are shown in Table 4.2. Column one identifies the sub-district and the item being described. Columns 2 through 6 are the deviation categories. The final column is the estimated number of typical call-outs made during an average year.

Operations foremen were then briefed on the type of information RWIS provide and the proposed implementation of the system. This included the type of information provided, the frequency information is updated, the documented accuracy of information, access to information and the number of remote sites where information would be available. Sample RWIS outputs shown to the sub-district operations foremen are located in Appendix A. They were then asked to estimate how their call-out decisions would change if they had RWIS information. The new decision distribution by deviation category is shown in Table 4.2.

Table 4.2: Decision Distributions and Frequency Change

[1] Sub-district	[2] Very EARLY #	[3] Slightly Early #	[4] On Target #	[5] Slightly Late #	[6] Very LATE #	[7] Total
Cloverdale						
Current information	2	6	6	5	1	20
RWIS information	0	6	12	2	0	20
Frequency change	2	0	-6	3	1	
Plymouth						
Current information	4	8	12	5	2	31
RWIS information	2	8	18	3	0	31
Frequency change	2	0	-6	2	2	
Tipton						
Current information	4	4	17	3	2	30
RWIS information	0	4	23	3	0	30
Frequency change	4	0	-6	0	2	

The decision distribution with old information was subtracted from the decision distribution with RWIS information to obtain the call-out decision frequency change for each deviation category. The shaded rows of Table 4.2 show the frequency change by deviation category that were estimated to result from using RWIS information. The following section implements the methodology for quantifying the annual direct benefits.

4.1.4 Quantifying Annual Direct Benefits

Sub-district operations foremen were asked to describe how the direct costs increase for each one of the deviation categories. Descriptions of the estimated increases in direct cost are summarized in Table 4.3. Column one identifies the sub-district. The subsequent columns show the responses for each deviation category as given by the sub-district operations foremen.

Increases in direct costs for early deviation categories were calculated by multiplying the number of hours early by the hourly cost for labor and equipment. The sub-district operations foremen indicated that material use was not affected by initiating the call-out early. Cost increases for late deviation categories were caused by

Table 4.3: Increased Cost Descriptions for Each Deviation Category

[1] Sub-district	[2] Very EARLY	[3] Slightly Early	[4] Slightly Late	[5] Very LATE
Cloverdale	6 hours of (material and equipment)	1hour of (material and equipment)	5 hours of (1.3 * material)	5 hours of (2.0 * material)
Plymouth	6 hours of (material and equipment)	1hour of (material and equipment)	4 hours of (1.3 * material)	4 hours of (2.5 * material)
Tipton	4 hours of (material and equipment)	1hour of (material and equipment)	5 hours of (1.3 * material)	5 hours of (1.7 * material)

increased material usage. Expenses for labor and equipment decreased slightly. The magnitude of the labor and equipment decrease, as suggest by the sub-district operations foremen, were 30 minutes for slightly late and 1 hour for very late. Total direct costs for each deviation are shown in Table 4.4. The first column identifies the sub-district. Columns two and three show the total cost of the early deviation categories using the modifications in Table 4.3. The fourth column is the total cost with no deviation from the target call-out as shown in Figure 4.2. Columns five and six show the total cost of the late deviation categories, again using the modifications from Table 4.3.

Cost increases for each deviation category were calculated by subtracting the total target call-out cost from the total cost for each deviation category. Results of this calculation are shown in Table 4.5. Deviation category frequency changes were multiplied by the increased direct cost to show categorical benefits resulting from the RWISinformation. Total benefits for each sub-district were the result of summing the benefits for all of the deviation categories, as shown in Table 4.5. Column one shows the sub-district and the description of each item. The next five columns are the deviation categories and the seventh column is the total annual direct benefits by sub-district. The final row of the table is shaded and shows the summation of the direct benefits. The next section implements the methodology for quantifying the annual indirect benefits.

Table 4.4: Total Cost for Each Deviation Category

[1] Sub-district	[2] Very EARLY $	[3] Slightly Early $	[4] On Target $	[5] Slightly Late $	[6] Very LATE $
Cloverdale	32,306	28,419	27,987	30,438	36,680
Plymouth	39,052	35,251	34,829	36,632	44,998
Tipton	23,706	21,997	21,678	22,963	24,773

4.1.5 Quantify Annual Indirect Benefits

Quantifying the annual indirect benefits of new information on snow and ice control mobilization has two main steps. First, calculate the volume of traffic affected by improving the call-out decision. Next, calculate the indirect volume benefits factors for decreased accidents, decreased travel time, and decreased fuel consumption in terms of dollars per vehicle kilometer traveled (VKT). The products of indirect volume benefit factors and affected volume are the indirect benefits.

Table 4.5: Annual Direct Benefits Resulting from RWIS Information

[1] Sub-district		[2] Very EARLY	[3] Slightly Early	[4] On Target	[5] Slightly Late	[6] Very LATE	[7] Sub-district Benefits $
Cloverdale							
	Frequency change	2	0	-6	3	1	
	Increased cost ($)	4,319	432	0	2,451	8,693	
	Benefits ($)	8,638	0	0	7,353	8,693	24,684
Plymouth							
	Frequency change	2	0	-6	2	2	
	Increased cost ($)	4,223	422	0	1,803	10,169	
	Benefits ($)	8,446	0	0	3,607	20,337	32,390
Tipton							
	Frequency change	4	0	-6	0	2	
	Increased cost ($)	2,028	319	0	1,285	3,095	
	Benefits ($)	8,111	0	0	0	6,191	14,302
Total Direct Benefits ($)							71,375

<u>Traffic Volume Benefiting from RWIS Information</u>

The indirect benefits were calculated by determining the volume of traffic affected by improving the call-out with RWIS information. Sub-district operations foremen were asked to estimate the increase in the amount of time that the road conditions were hazardous for each deviation category. They indicated that there was no increase in the amount of time the roads were hazardous for either of the early call-out deviation categories. The responses for the time increase of hazardous road conditions for the late deviation categories are shown in Table 4.6. Total time reductions of hazardous road conditions, for each deviation category, were calculated by multiplying the increased time by the call-out decision frequency change determined in the previous section. The results of this calculation can be seen in Table 4.6. Column one identifies the sub-district and the item being described. Columns two and three show the late deviation categories. The final column is the total time reduction of hazardous road conditions for each sub-district.

Table 4.6: Total Time Reduction of Hazardous Road Conditions

[1] Sub-district		[2] Slightly Late	[3] Very LATE	[4] Total min
Cloverdale				
	Time increase (min.)	120	240	
	Frequency change	3	1	
	Time reduction (min.)	360	240	600
Plymouth				
	Time increase (min.)	65	135	
	Frequency change	2	2	
	Time reduction (min.)	130	270	400
Tipton				
	Time increase (min.)	45	75	
	Frequency change	0	2	
	Time reduction (min.)	0	150	150

The volume of traffic not exposed to hazardous road conditions was calculated for two-lane and four-lane highways using the time reduction of hazardous road conditions. This calculation had three steps: 1) calculate annual average daily traffic volumes, 2) adjust traffic volumes to account for winter weather, and 3) multiply time reduction by the adjusted traffic volume. The annual average daily traffic volumes were calculated by multiplying the annual average daily traffic count (AADT) (Division of Roadway Management, 1992 & 1993) by the road segment lengths (INDOT Inventory Maintenance Management System, 1995). The volume calculations for each sub-district can be seen in Appendix B. Table 4.7 shows two-lane and four-lane highway traffic volumes for each sub-district.

The annual average daily traffic volume had to be adjusted to account for winter weather volume reductions. Traffic volume reduction due to winter weather is related to the depth of snow. The sub-district operations foremen suggested that the depth of snowfall for the typical call-out was less than 75 mm (~3 in.). Traffic volume reduction corresponding to a depth of snow between 25 mm and 75 mm (~ 1-3 in.) was estimated to be 11-25 percent on weekdays and 30-41 percent on weekends (Hanbali and Kuemmel, 1993). A conservative volume reduction of 25 percent was selected for this research. The adjusted traffic volumes are shown in Table 4.7. These adjusted daily traffic volumes were multiplied by the time reduction in hazardous road conditions, taken from Table 4.6, which resulted in the volume of traffic not exposed to hazardous road conditions, as shown in Table 4.7. Column one identifies the sub-district. Column two is road type by sub-district. Columns 3 and 4 are the unadjusted traffic volume and the adjusted daily traffic volume, respectively. Column five is the time reduction in hazardous road conditions. Lastly, column six is the volume of traffic not exposed to hazardous road conditions. The next section calculates the indirect benefit volume factors.

Table 4.7: Volume of Traffic Avoiding Hazardous Road Conditions

[1]	[2]	[3] Total Volume vkt/day	[4] 25% Reduced Volume vkt/day	[5] Decreased Hazard Time min.	[6] Decreased Hazard Volume vkt
Cloverdale	Two lane	1,142,000	856,500	600	357,000
	Four lane	3,146,000	2,359,500	600	983,000
Plymouth	Two lane	1,926,000	1,444,500	400	401,000
	Four lane	2,409,000	1,806,750	400	502,000
Tipton	Two lane	1,961,000	1,470,750	150	153,000
	Four lane	2,748,000	2,061,000	150	215,000
	Two lane total				911,000
	Four lane total				1,700,000

Indirect Benefit Volume Factors

The indirect benefit volume factors were calculated for reduction in accidents, decreased travel time and decreased fuel consumption. The procedure for calculating these volume factors was based extensively on work by Hanbali (1994). The benefit factors were calculated for two-lane and four-lane highways. Many of the components used to calculate the indirect volume factors needed to be expressed in current study dollars, 1994.

The accident volume factors have two components. First, there are the costs of different accident types. Second, there are the accident reduction rates. Accident costs are generally broken down by type of accident. Common accident classifications are: fatal accident, injury accident, and property damage only accident. Two recent estimates for the costs of these accidents were considered.

The Federal Highway Administration (FHWA) (Urban Institute, 1991) published estimated accident costs in 1990 dollars. The cost estimates included medical expenses, emergency service, workplace costs, travel delay, property damage, and administrative and legal out-of pocket expenses. The actual dollar numbers of the cost estimates, after being adjusted to 1994 dollar value using the CPI, are shown in Table 4.8. Column one describes the accident type. Subsequent columns are the estimated accident costs in 1994 dollars list by estimator.

The second estimate of accident costs was performed by the National Highway Traffic Safety Administration (NHTSA) (NHTSA, 1993). The cost estimates, in 1992 dollars, included medical expenses, emergency service, vocational rehabilitation, market productivity, workplace cost, administrative and legal costs, travel delay, and property damage. The actual dollar numbers of the cost estimates, after being adjusted to 1994 dollar values, are shown in Table 4.8. In order to be conservative, the NHTSA estimates of accident costs were used to calculate the accident benefit factor.

Table 4.8: Accident Cost Estimates

[1] Accident types	[2] FHWA $ (94 CPI)	[3] NHTSA $ (94 CPI)
Fatal	3,344,989	786,557
Injury	85,496	15,997
Property Damage Only	5,556	1,676

Accident rate reductions used to determine the accident benefits in this analysis were determined by Hanbali (1994). The accident reductions are for property damage only and personnel injury accident rates, for two-lane and four-lane highways, in term of millions of vehicle kilometers traveled (MVKT), as shown in Table 4.9.

The product of the accident reduction rates and the accident costs yield the accident benefit volume factors. The accident benefit volume factors for two-lane and four-lane highways are shown shaded in Table 4.9. Column one describes the road and accident type. Column 2 shows the accident reduction rates from Hanbali (1994). The third column shows the NHTSA accident cost estimates in 1994 dollars. Column four is the individual accident benefit in dollars per MVKT. The fifth and sixth column are the individual and total volume benefit factors in dollars per VKT.

Table 4.9: Accident Benefit Volume Factors

[1] Two lane	[2] Accident Reduction acc / mvkt	[3] NHTSA $ / acc	[4] NHTSA $ / mvkt	[5] Individual Acc. Benefit $ / vkt	[6] Volume Factor $ / vkt
Injury	4.41	15,997	70,546	0.071	
Property Damage	2.51	1,676	4,207	0.004	0.0748
Four lane					
Injury	2.18	15,997	34,873	0.035	
Property Damage	0.48	1,676	804	0.001	0.0357

The travel time volume factors had three main inputs. They include vehicle speed reduction, average normal travel speed and the estimated vehicle cost per hour. The issue of vehicle speed reduction related to snow and ice road conditions was addressed by McBride (1977). McBride reported the average ranges of vehicle speed reduction were 18-42 percent and 13-22 percent on two-lane and four-lane highways, respectively. Conservative estimates of 25 percent and 15 percent on two-lane and four-lane highways, respectively, were used for the vehicle speed reductions. The normal average travel speeds were assumed to be 72 kilometers per hour (KMH) (~45 mph) and 90 KMH (~55 mph) for two lane and four lane highways, respectively. The travel time reduction from improving the call-out was the inverse of the reduced speed minus the inverse of the normal speed. A vehicle cost of $3.00 per hour, based on a 1975 estimate, was obtained from the AASHTO manual (1977). The AASHTO figure was inflated to 1994 dollars using the CPI. Calculating the travel time benefit factor was the product of the inflated AASHTO cost per vehicle hour and the travel time reduction, as shown shaded in Table 4.10. Column one describes the highway type. Column two is the speed reduction percentage. The third and fourth columns are the normal and reduced speeds respectively. The fifth and sixth columns are the travel time reduction and the hourly value of a vehicle. Lastly, column seven shows the travel time benefit volume factors for the types of highways.

Table 4.10: Travel Time Benefit Volume Factors

[1] Type	[2] Speed Reduction %	[3] Normal Speed kmh	[4] Reduced Speed kmh	[5] Travel Time Reduction hour/vkt	[6] AASHTO Cost (94) $/hour	[7] Volume Factor $/vkt
Two lane	25	72	54	0.005	$8.26	0.0383
Four lane	15	90	77	0.002	$8.26	0.0162

Fuel consumption benefits are a function of four inputs. They include travel speed, dry pavement fuel consumption, snowy pavement fuel consumption, and the price of gasoline. The regular and reduced speed used for the travel time benefit was also used in the fuel consumption calculations. The fuel consumption traveling on dry pavement at the regular speed was gleaned from work done by Claffey (1976). Claffey created a series of curves that were a function of fuel consumption, travel speed, and pavement snow depth, as shown in Appendix C. Before determining the fuel consumption from traveling on snowy pavement, the depth of snow on the road had to be estimated. A value of 12 mm (~0.5 in) was used as the snow depth. Knowing the pavement snow depth and the reduced travel speed, the fuel consumption was obtained from the Claffey (1976) curves. Lastly, the price of gasoline had to be determined. This was done by calculating the average of the CPI monthly gasoline prices for October, November, December, January, February, and March 1994 (Bureau of Labor Statistics, 1995). Calculating the fuel consumption benefit volume factor was the product of the difference in fuel consumption and fuel price, as shown shaded in Table 4.11. Column one describes the highway type. The second and third columns are the normal and reduced speeds, respectively. The fourth and fifth columns are the fuel consumption on dry and snow covered pavement, respectively. Column six is the price of gasoline per liter. Lastly, column seven shows the fuel consumption benefit volume factors for the types of highways.

Table 4.11: Fuel Consumption Benefit Volume Factor

[1] Type	[2] Normal Speed kph	[3] Reduced Speed kph	[4] DRY l/km	[5] 12mm/.5" l/km	[6] Diff. l/km	[7] Fuel Price $/l	[8] Volume Factor $/vkt
Two lane	72	54	0.023	0.026	0.003	0.285	0.0007
Four lane	90	77	0.027	0.028	0.001	0.285	0.0003

The inputs required to calculate the indirect benefits were the benefit volume factors shown in Tables 4.09, 4.10, 4.11 and the volume of traffic affected by improving the call-out shown in Table 4.08. The volume factors for the reduction in accidents, travel time and fuel consumption were multiplied by the volume of affected traffic to determine the individual benefits, as shown in Table 4.12. The total indirect benefits of acquiring RWIS information was the summation of the individual indirect benefits components. Column one describes the road type and indirect benefit type. The second column is the benefit volume factors. Column three is the affected traffic volume for each road type. Lastly, column four is the benefit by type. The final row of the table is shaded and is the summation of all indirect benefits. The following sections present the results from expanding the benefits statewide.

Table 4.12: Indirect Benefits resulting from RWIS information

[1] Two lane	[2] Volume Factor $ / vkt	[3] Affected Volume vkt	[4] Individual Benefits $
Accident	0.0748	911,000	68,100
Travel Time	0.0383	911,000	34,854
Fuel Consumption	0.0007	911,000	662
Four lane			
Accident	0.0357	1,700,000	60,652
Travel Time	0.0162	1,700,000	27,546
Fuel Consumption	0.0003	1,700,000	506
Total Indirect Benefits ($)			192,320

4.1.6 Statewide benefits expansion

Step 6 of the benefit determination methodology is the expansion of the benefits statewide. This was done in two ways, uniform expansion and proportional expansion.

The uniform benefit expansion assumes that all sub-districts would benefit equally from the additional RWIS information. The uniform benefit expansion factor was calculated by taking the total number of sub-district, thirty-seven, divided by the number of representative sub-district, three. The result of that calculation was 12.33.

The proportional benefit factor assumes that benefits are proportional to the amount of money spent on snow and ice control operations. Data for this calculation was obtained from the INDOT maintenance management system. The system only had data for the 1992-93 and 1993-94 seasons. The benefit factor was calculated by taking the average amount of money spent on snow and ice control each year by the entire state, $19,981,000, and dividing that by the average amount the representative sub-districts spent, $2,705,000. The resulting expansion factor was 7.39. The expanded benefits are shown in Table 5.13. The first column identifies the benefit type. Column two is the total benefits for the representative sub-districts. The third and fourth columns are the rounded benefits expanded using the uniform and proportional factor, respectively. The following section presents the results from determining how to quantify the costs of implementing RWIS technology for the INDOT.

Table 4.13: Expanding Benefits Statewide

[1] Benefit Type	[2] Representative Sub-district Total ($)	[3] Uniform Expansion [12.33] ($)	[4] Proportional Expansion [7.39] ($)
Direct	71,375	880,000	527,000
Indirect	192,320	2,372,000	1,421,000
TOTAL	263,695	3,252,000	1,948,000

4.2 Quantify Cost of RWIS for INDOT

Quantifying the costs of implementing RWIS technology for INDOT had two steps: 1) determine the desired implementation, and 2) determine the costs of the desired implementation in terms of initial and annual costs. The main issue in determining the implementation was to determine how many remote processing units (RPUs) would be sufficient. The number of central processing units (CPUs) and the communication structure depend on the number of RPUs and the existing communication infrastructure. There were two main sources of information for deciding the desired implementation, RWIS vendors, and other states who have previously implemented RWIS technology. The RWIS vendor indicated that the usual configuration was to place remote processing units (RPUs) on a grid pattern throughout the state. The size of this grid is often approximately sixty kilometers although occasionally the size is thirty kilometers (Evans, 1995). The vendor also indicated that a common RPU configuration included a processing computer, four pavement sensors, a sub-surface probe, and a weather station.

In addition, several midwestern states had or were in the process of implementing statewide RWIS technology, notably, Iowa, Minnesota, and Wisconsin. The number of actual and proposed RPUs for each of these states as well as the areas of the states are shown in Table 4.14. In order to determine the approximate grid spacing other states implemented, the area of the state was divided by the number of RPUs, as shown in Table 4.14. Column one is shows the state being described. Column two is the number of RPUs that were implemented. The third column is the area of the state and the fourth column is the approximate grid spacing of the RPUs.

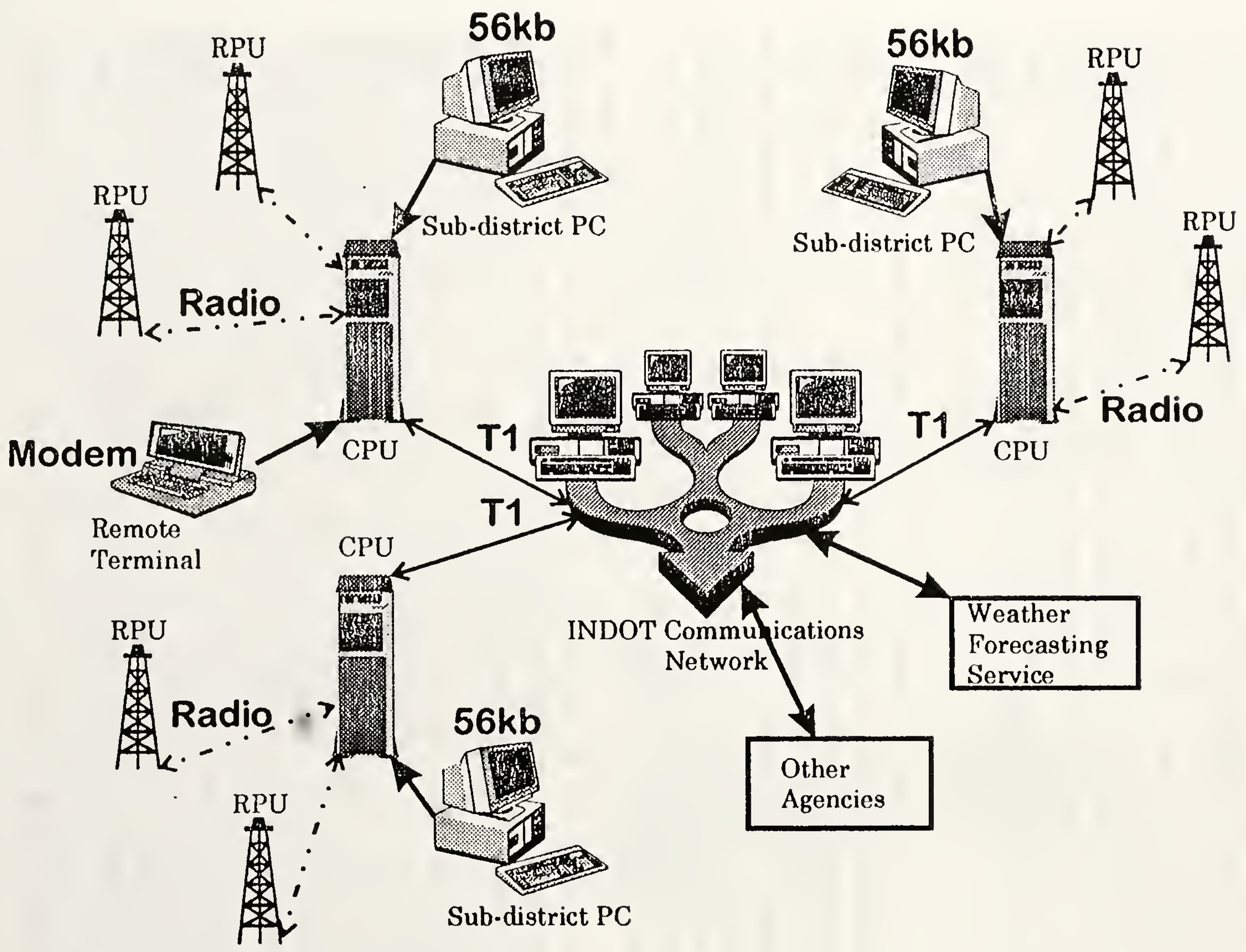
Table 4.14: Other States RPU implementation

[1] States	[2] RPUs #	[3] Area km^2	[4] Approximate Grid spacing km
Iowa	48	145,754	55
Minnesota	276	225,182	29
Wisconsin	53	169,653	57
Indiana	??	94,328	??

The approximate spacing of the RPUs for Iowa and Wisconsin were close to the common sixty kilometer spacing. However, Minnesota is very close to the thirty kilometer spacing. If Indiana was to adopt a sixty kilometer grid, the number of RPUs would be the area of the state divided by 60 kilometers squared. The result of this calculation is approximately twenty six. In order to maintain equity between the sub-districts the number of RPUs was increased to thirty-seven, the number of sub-districts. The resulting grid spacing would then be approximately 50 kilometers. Each RPU included a processing computer, four pavement sensors, one sub-surface probe and a weather station.

The next issue to determine was the number of central processing units. The vendor indicated that the number of CPUs varies greatly. Each state had different CPU configurations. The number of central processing units used depends the number of RPUs and on the communication configuration selected. The number of CPUs selected for this study was seven. The CPUs would be located at each one of the districts and at the INDOT central office. Again, This was done to maintain equity within the state as well as to utilize the existing communication infrastructure. The state will have, within the year, high bandwidth communications between the all districts and from all sub-districts to their district (Swinford, 1995). The communications between the CPUs as well as from the sub-district to CPU will be handled by the existing state communications infrastructure. The only remaining implementation detail was the communication from the RPU to the CPU.

The communication configuration options between RPU and CPU were discussed in a Minnesota task force report (MinDot, 1993). The Minnesota task force reviewed three communication options including leased phone lines, satellite communications, and radio communications. Radio communications were found to the most economical in terms of initial investment and monthly maintenance.



4.3: Conceptual Indiana RWIS Communications

4.2.1 Initial Costs

The costs for each component were almost entirely based on the Iowa Road Weather Information System Report (Smith, 1994). The exception to this was the communications between RPU and CPU that were taken from the Minnesota task force report (MinDOT, 1993) and the site forecasts which were established through a vendor estimate (Webb, 1995). The costs are broken down into initial and annual costs. Initial costs include RPU hardware and installation, CPU hardware and installation, sub-district hardware, software and installation, as shown in Table 4.14. Column one describes the costs and column two is the estimated cost. A more detailed description of the initial costs can be seen in Appendix D.

Table 4.14: Initial Costs for RWIS Implementation

[1] Item Description	[2] Price $
Hardware for RPUs	1,752,894
Installation for RPUs	1,002,700
Hardware for CPUs	131,320
Hardware and services for the sub-districts	282,939
Total initial investment	3,170,000

4.2.2 Annual Costs

The annual costs were separated into two categories, first year operational costs and additional year operational costs. These costs included RPU and CPU communications, remote access communications, RPU vendor forecasting service, training and maintenance. Both annual cost categories are shown in Table 4.15. Column one describes the costs. Column two and three are the first year and additional year operational costs, respectively. A more detailed description of the annual costs can be seen in Appendix D.

4.3 Comparison of Benefits and Costs

Given the initial investment and the yearly benefits and costs, a benefit-cost analysis was performed. This had three components: 1) determine the investment horizon and inflation rate, 2) calculate the equivalent annual cash flows for benefits and costs, and 3) calculate the various benefits costs ratios. The following section determines the investment horizon and inflation rate.

Table 4.15: Annual operational costs for RWIS

[1] Item Description	[2] Year 1 $	[3] Additional Years $
Radio communications between RPU and CPU	34,595	34,595
Remote user to CPU	688	688
Weather forecasting	64,380	64,380
Training	49,200	16,400
Service/ Maintenance RPUs	0	111,000
Total	114,000	192,000

4.3.1 Determine Investment Horizon, Inflation Rate and Market Interest Rate

The investment horizon depends greatly on policies of the organization considering the investment. To that end, the head operations support for INDOT was asked what investment horizons were usually used to evaluate projects. He replied that the investment horizons varied but rarely exceeded ten years (Goode, 1995). Using this information and because of large initial investment, a ten year investment horizon was selected.

The future inflation rate was estimated by using historical inflationary information. It was estimated to be equal to the average inflation of a historical period equal in length to the investment horizon. Since the investment horizon was set to ten years, the estimated inflation rate was the average inflation rate from 1984 to 1994. This rate was calculated using the Consumer Price Index (CPI). As mentioned previously in section 3.2.1, this index is being used exclusively to account for inflation. The average inflation rate for the period 1984 to 1994 was calculated to be approximately 3.6%.

The next step was to determine the market interest rate. The market interest rate should reflect at least the government's cost to borrow money. The prime interest rate was used to estimate the government's cost to borrow money. The current prime rate of 9% was used for the market interest rate in this analysis.

4.3.2 Calculate the Equivalent Cash Flows for Benefits and Costs

Equivalent cash flows were calculated for benefits and costs using the investment horizon and the inflation rate. This was completed in a three step process: 1) inflating the annual benefits and the cost cash flows over the investment horizon, 2) calculating the net present value of the inflated annual benefit and cost cash flows, and 3) determine the equivalent annual cash flow for present value of all costs and benefits. The annual cost and benefits were inflated using the estimated inflation rate of 3.6%, as shown in Figure 4.4.

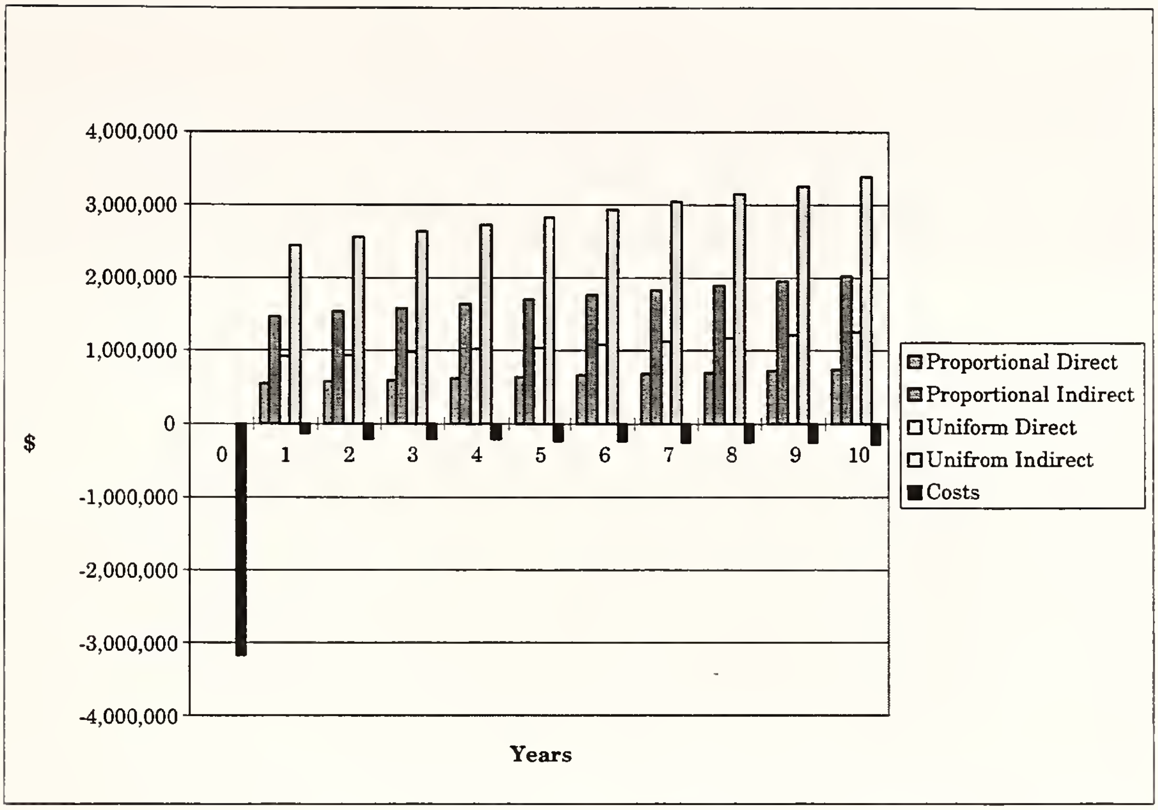


Figure 4.4: Inflated Annual Benefit and Costs

The present values of the inflated cash flows were calculated using the market interest rate of 9%. The equivalent ten year annuity was calculated for the present values again using the market interest rate of 9%, as shown in Table 4.15. Column one describes the item. Column two shows the cost values. Columns three and four show the direct and indirect uniform benefit values, respectively. The fifth and sixth columns show the direct and indirect proportional benefit values, respectively.

Table 4.15: Present Values and Amortized Annuities of Benefits and Costs

		Uniform Benefits		Proportional Benefits	
[1] Item	[2] Costs $	[3] Direct $	[4] Indirect $	[5] Direct $	[6] Indirect $
Present Values	-4,659,327	7,399,748	19,945,685	4,431,440	11,948,912
Ten Year Annuity	-563,000	894,000	2,410,000	536,000	1,444,000

4.3.3 Calculate Benefit-Cost Ratios

The final stage in the comparison was calculating the benefits cost ratios. Three types of benefit-cost ratio were used, direct benefits-total costs, indirect benefits-total costs, and total benefits-total costs. The three types of benefit-cost ratios were calculated for both uniform and proportional benefits, as shown in Table 4.16. This was done by taking the respective annual benefit and dividing it by the total annual cost. Column one is the description of the benefit-cost ratio. The second and third columns are the ratios for uniform and proportional benefits, respectively. The following chapter discusses the results of this implementation, critiques the methodology and present directions for future work.

Table 4.16: Benefit-Cost ratios

[1] Description	[2] Uniform Benefits	[3] Proportional Benefits
Direct Benefits / Total Costs	1.48	0.88
Indirect Benefits / Total Costs	3.98	2.38
All Benefits / Total Costs	5.45	3.26

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

This Chapter has three components. The first is a study summary. This is followed by a critique of the methodology. The chapter concludes by suggesting directions for future work.

5.1 Study Summary

5.1.1 Concept

Timing of snow and ice control call-outs has a large impact on the efficiency of real-time operations. Making the call-out too early uses labor and equipment resources when there is not yet a need for them. Late call-outs also decrease operational efficiency by increasing material usage, travel time, fuel consumption and accident risk. Traditional sources of weather information available to snow and ice control decision makers have not proven effective in improving call-out timing. New sources of information exist that may be used to improve the ability to make effective call-outs. It is important to be able to determine if the cost of a new information source is recoverable through the benefits derived from its use.

5.1.2 Methodology

A methodology for evaluating the benefit of additional information in snow and ice control mobilization was presented. There are three main components of the evaluation methodology, determine benefits, determine costs, compare benefits to costs. Determining benefits consists of calculating the benefits by comparing the call-out decisions using old information to the call-out decisions using new information. Costs are determined by calculating the initial and annual costs of implementing the new weather information. The benefit-cost analysis is the comparison of benefits and costs in a ratio to ascertain if adopting the new weather information is a sound management decision.

5.1.3 Implementation Results

This methodology was implemented to evaluate road weather information systems (RWIS) for the Indiana Department of Transportation (INDOT). Benefits included in the analysis were classified in two types, direct benefits and indirect benefits. Direct benefits included labor, equipment, and material cost reductions. Indirect benefits included the reductions in accidents, travel time and fuel consumption. Benefits and costs were compared using a ten year investment horizon. Benefit-cost ratios ranged from 0.88 to 5.45, as shown in Table 5.1. The lower ratio was the comparison between direct benefits only, expanded in proportion to sub-district resource expenditures, and total costs. The higher ratio was the result of comparing total benefits, expanded uniformly, to total costs. All generated benefit-cost ratios are shown in Table 5.1. Column one describes the benefits and costs included. Column two and three are the ratios using a proportional and uniform benefit expansion, respectively.

Table 5.1: Benefit-Cost Ratios for INDOT Acquiring RWIS Technology

[1] Description	[2] Uniform Benefits	[3] Proportional Benefits
Direct Benefits / Total Costs	1.48	0.88
Indirect Benefits / Total Costs	3.98	2.38
All Benefits / Total Costs	5.45	3.26

5.1.4 Other Benefits of RWIS

In addition to the tangible benefits quantified in this analysis, there are certain intangible benefits that are affected by improving the information available for making the call-out. Improving the call-out reduces environmental impact by decreasing the application of corrosive, environmentally harmful chemicals. Having better information also reduces the stress on the snow and ice control decision maker. Finally, improving the timing of the call-out increases the public perception of the quality of management within the INDOT.

Acquiring RWIS technology appears to be a justified expense based on the conservatively estimated benefits from improving the call-out timing. It has been suggested by Yamin (1991) and Balgowan (1987) that RWIS information also improves material management during the storm and can be used to avoid questionable call-outs. Improved material management would result from using the pavement temperature and chemical factor information to vary material application rates (Balgowan, 1987). Yamin (1991) indicated that by using pavement temperature readings, snow and ice control personnel in Indianapolis avoided using chemicals during a 7.5 inch snowfall. The pavement was warm enough to melt the snow without the aid of chemicals. In some cases the pavement temperatures will be high enough that a call-out may be avoided all together.

Accurate real and forecasted pavement and weather information are helpful in other areas besides snow and ice control. Summer pavement temperature forecasts can be used by construction personnel for scheduling paving activities. In addition, pavement information can be used in traffic incident prediction. Incident prediction uses pavement temperature, travel speed and other inputs to estimate the probability of traffic incidents. When the probability of an incident is high, transportation officials can allocate resources to aid in minimizing the effect of the incident. RWIS weather information could also be used as model inputs to predict the movement of contaminant plumes created by accidents involving vehicles carrying hazardous materials.

5.2 A Critique

This section is a critique of the methodology developed to evaluate the benefit of additional information used in snow ice control mobilization. The section is divided into two sub-sections, strengths of the proposed methodology and weaknesses of the proposed methodology.

5.2.1 Strengths of the Proposed Methodology

There are strengths in all three components of the methodology. Strengths in the benefit determination are that the analysis takes into account both direct and indirect benefits and that decision comparisons can be varied by adding or deleting deviation categories. The strength of the cost determination is that prices used in the determination are easy to substantiate. The comparison methodology is strong because it is a well established and flexible.

Benefit Determination Strengths

Strengths in the benefit determination are that the analysis takes into account both direct and indirect benefits and that decision comparisons can be varied by adding or deleting deviation categories. Using both indirect and direct benefits, but calculating them separately, give a more complete picture of the effects of adopting a new technology. Often times, the indirect benefits are ignored because they are more difficult to quantify. Providing the policy maker with information about both types of benefits allows a more informed decision to be made about adopting a new technology. An additional strength is that decision comparisons can be varied by adding or deleting deviation categories. This gives the methodology more flexibility. If data exist to categorize the cost profile in more detail, the approximation of benefits will improve.

Cost Determination Strength

The strength of the cost determination is that prices used in the determination are easy to substantiate. Accurate prices can be established by contacting various vendors and other states that have previously implemented the information source.

Strengths of the Comparison

The comparison methodology is strong because it is a well established and flexible. Benefit-cost ratios are a common framework for evaluating public sector projects. In addition, the investment horizon and interest can be changed to provide additional insight to the decision maker.

5.2.2 Weaknesses of the Proposed Methodology

There are two potential weaknesses of the benefit determination methodology proposed in this research. The first potential weakness is using the unsubstantiated typical call-out as the method of comparison. Using a small representative group to calculate and expand the benefits is the second potential weakness.

Benefit Determination Weaknesses

One of the potential weaknesses with this methodology is using a typical call-out developed using the expertise and experience of snow and ice control decision makers for the basis of comparison. The author acknowledges that the development of a typical call-out is subjective and difficult to substantiate without further data collection. One possible attempt to verify the typical call-out development is to compare the estimated total sub-district expenses, using the typical call-out, with historical sub-district expenses. Estimating the total expenses using the typical call-out can be accomplished by taking the summation of the total storm costs for each deviation category multiplied by the number of call-out occurrences in that category using current information. These numbers can be compared to the historical snow and ice control expenses from the INDOT maintenance management computer system. Table 5.2 shows the result of this comparison. Row one is the typical call-out total expenses. Row two and three are the historical snow and ice control expenses. Row four and five are the ratios of the typical total cost divided by the historical total cost.

The ratios of estimated total expenses to historical expenses suggest that the typical call-out development was fairly accurate, although maybe slightly conservative. The main problem with using this means of validation is the possibility that the estimated costs are high and the

Table 5.2: Total Cost Comparison

	Description	Cloverdale $	Plymouth $	Tipton $
[1]	The summation of the each deviation category total cost * the number of call-out occurances in that deviation category using current info	591,923	1,129,319	669,777
[2]	1992-93 historical expenses	539,071	1,333,722	823,007
[3]	1993-94 historical expenses	743,882	1,054,634	915,286
[4]	Ratio (developed / 1992-93 historical)	1.10	0.85	0.81
[5]	Ratio (developed / 1993-94 historical)	0.80	1.07	0.73

estimated frequencies of events are low, or vice versa. This would result in similar cost totals even though an error in the call-out estimation would exist.

Another potential weakness of the implementation of the methodology is the small representative group. The benefits were expanded statewide based on 3 of 37 sub-districts. Each sub-district operations foreman may use information differently in their decision process. Sub-districts may have different resource constraints. In addition, the network characteristics of the sub-districts can also vary. In order to account for these variations, benefits were expanded using two methods. Ideally, the representative group would be larger to account for the above variations.

5.3 Recommendations for Further Research

This section recommends directions for further research. It is broken down into three parts, improving the evaluation methodology, examining other technologies, and a finer resolution implementation.

5.3.1 Improving the Evaluation Methodology

An area for improvement might be obtaining better data. During the course of this research the lack of data made accurately quantifying certain aspects of winter snow and ice control operations difficult. Currently, data are archived in terms of aggregate expenditures. It is suggested that some new form of data archiving be adopted. The new data archiving should have contextual information describing how and when decisions were made as well as information about quantity of resources being used. Ideally this information would be in a digital format for ease of searching and processing.

Another possible option for improving the evaluation methodology would be to expand the group of representative snow and ice control decision makers. This would help account for varying decision making styles, different resource constraints, and different network characteristics.

5.3.2 Examining Other Technologies

The addition of the World Wide Web (WWW) to the Internet has made the once syntactically intimidating Internet usable by most novices. Multimedia is an important part of the interaction of the WWW. This addition of sound, images and video makes it an ideal source for transmittal of weather information.

There are several pertinent examples of effective information dissemination already available on the WWW. The Purdue atmospheric science department has a weather server running on the WWW, which includes recent regional satellite and radar images (Earth and Atmospheric Sciences and Purdue University, 1995). There are also several other modified weather related images available. Another excellent example of a transportation related use of the WWW is the Maxwell Laboratories, Inc. and CALTRANS WWW server (Caltrans et al., 1995). This server creates real-time traffic congestion images for major cities in California, which any motorist can use to plan their travel. Given this additional information, a motorist can make better decisions concerning their route. More informed decisions can save the motorist a great deal of time as well as help avoid added congestion.

This type of information dissemination could be used in all areas of transportation both by the users and service providers. The weather server concept could be taken further by tailoring the weather information for a specific audience on a regional level, i.e., snow and ice control personnel. This could provide winter maintenance personnel with an option most weather information technologies do not have: the capacity to interact. Not only can they interact and get the information needed but they can do so in many different information formats. In addition, a similar approach could be taken, for providing tailored weather information to the traveling public.

5.3.3 Finer Resolution Implementation

The implementation of the methodology could be altered and made finer. Each sub-district could conduct their own analysis using the proposed methodology. The new study could be conducted over a specific time period. Snow and ice control personnel could record their call-out decisions and monitor storm costs and characteristics. Monitoring storm costs and characteristics would increase the accuracy of the typical call-out. Recording call-out decisions would improve the accuracy of the call-out decision distribution using current information. The decision makers would still have to estimate their call-out decision distribution using new weather information to facilitate the comparison between benefits and costs.

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APPENDICES

APPENDIX A

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                    SCANCAST(sm) _______ PAVEMENT   Forecast
                   SCAN  Highway  &  Runway  Prediction  Model
   CITY OF INDIANAPOLIS        Issued: Dec 18 12:29 EST
    Valid 24 hours starting at  12pm Dec 18 1990

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23 Chill 18        20        25        24        28        27        29        29
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RAIN CHANGING TO WET SNOW EARLY THIS AFTERNOON. SNOW ENDING BETWEEN 5PM AND
8PM WITH SOME ACCUMULATION ON GRASS. WORST CASE COULD SEE SOME SLUSH
ACCUMULATE ON BRIDGES TOWARD END OF SNOW. CLOUDY TONIGHT. VARIABLE CLOUDS
TOMORROW.
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F=print file in black and white        S=print screen in color       Esc=exit
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Figure A.1: Typical RWIS Sample Output

Table A.1: Typical RWIS Sample Output

Long Term History Page
Indianapolis Int'l Airport, IN
Sensor #17

Date	Time	Status	CF	Precip	Temperatures Surf.	Air	Dew	Wind Dir	Vel
01/25/91	20:38	Dry		N	21	19	4	/	
01/26/91	00:06	Dry		Y	22	19	5	/	
01/26/91	00:21	Snow/Ice Alert	5	Y	22	19	6	120/	6
01/26/91	01:01	Snow/Ice Alert	15	Y	19	19	11	/	
01/26/91	01:11	Chemical Wet	45	Y	19	19	12	/	
01/26/91	10:48	Chemical Wet	35	Y	26	22	19	240/	4
01/26/91	10:54	Chemical Wet	35	Y	27	22	19	270/	5
01/26/91	11:06	Chemical Wet	50	Y	28	23	19	260/	7
01/26/91	11:13	Chemical Wet	85	Y	28	23	19	260/	7
01/26/91	11:31	Chemical Wet	95	Y	29	23	18	270/	11
01/26/91	11:34	Chemical Wet	95	Y	30	23	18	270/	10
01/26/91	11:39	Chemical Wet	95	Y	31	23	18	270/	12
01/26/91	11:43	Chemical Wet	95	Y	32	23	18	280/	12
01/26/91	11:56	Chemical Wet	95	Y	31	23	18	280/	18
01/26/91	12:06	Chemical Wet	95	Y	30	23	18	280/	12
01/26/91	12:11	Chemical Wet	90	Y	32	23	17	270/	9
01/26/91	12:14	Wet	95	Y	33	23	17	270/	13
01/26/91	12:19	Chemical Wet	95	Y	32	23	17	280/	11

Use arrow keys, PgUp, PgDn, Home, End , or Esc for command line

Long Term History Page
Indianapolis Int'l Airport, IN
Sensor #17

Date	Time	Status	CF	Precip	Temperatures Surf.	Air	Dew	Wind Dir	Vel
01/26/91	12:11	Chemical Wet	90	Y	32	23	17	270/	9
01/26/91	12:14	Wet	95	Y	33	23	17	270/	13
01/26/91	12:19	Chemical Wet	95	Y	32	23	17	280/	11
01/26/91	12:23	Chemical Wet	75	Y	31	22	16	290/	16
01/26/91	12:31	Chemical Wet	85	Y	30	22	16	270/	11
01/26/91	15:23	Dry		N	34	25	14	220/	15
01/26/91	15:36	Absorption	5	N	34	25	14	230/	10
01/26/91	15:38	Dry		N	34	25	14	220/	10
01/26/91	15:44	Absorption	45	N	34	25	14	240/	17
01/26/91	15:48	Absorption	5	N	33	23	13	240/	15
01/26/91	16:01	Dry		N	33	25	14	250/	17
01/26/91	16:09	Dry		N	32	23	13	240/	15
01/26/91	16:28	Dry		N	31	25	14	240/	16
01/26/91	16:41	Dry		N	30	23	13	250/	11
01/26/91	16:53	Dry		N	29	25	14	250/	8
01/26/91	17:04	Dry		N	28	23	13	250/	11
01/26/91	17:16	Dry		N	28	23	13	260/	8
01/26/91	17:36	Dry		N	25	23	13	240/	10

Use arrow keys, PgUp, PgDn, Home, End , or Esc for command line

APPENDIX B

Table B.1: Cloverdale Volume Calculations 1

Cloverdale Sub-district					
Road	Segment Description	ADT	Length Mile	Volume Mile/Day	Volume Km/Day
I 70	Clay County line to SR 243	20,090	8.13	163,332	262,964
	SR 243 to US 231	32,670	4.02	131,333	211,447
	US 231 to Morgan County line	32,800	8.19	268,632	432,498
	Putnam County line to IR 77	23,060	1.35	31,131	50,121
	IR 77 to Hendricks County line	25,370	7.78	197,379	317,780
	Hend. Co. line to Hend. Co. line	30,570	0.98	29,959	48,233
	Morgan Co. line to SR 39	35,250	2.13	75,083	120,883
	SR 39 to Morgan Co. line	32,320	0.85	27,472	44,230
	Morgan Co. line to SR 267	32,320	5.63	181,962	292,958
	SR 267 to Marion Co. line	45,270	2.95	133,547	215,010
	I-70 TOTAL		42.01	1,239,828	1,996,123
US 36	Parke County line to IR 385	3,230	3.10	10,013	16,121
	600 West to US 231	3,620	3.69	13,358	21,506
	US 231 to IR 51	3,830	1.72	6,588	10,606
	25 West to Locust St.	5,250	2.15	11,288	18,173
	Locust St. to Washinton St.	6,390	0.08	511	823
	Washington St. to Hend. Co. line	5,380	6.66	35,831	57,688
	Putnam County line to SR 75	4,280	1.90	8,132	13,093
	SR 75 to IR 21	5,420	4.77	25,853	41,624
	200 W. to Mackey Rd.	7,360	1.23	9,053	14,575
	Mackey Rd. to SR 39	10,710	0.27	2,892	4,656
	SR 39 to Kentucky St.	13,130	0.29	3,808	6,130
	Kentucky St. to SR 39	18,190	0.06	1,091	1,757
	SR 39 to OLD US 36	18,270	1.02	18,635	30,003
	OLD US 36 to IR 65	12,050	3.97	47,839	77,020
	525 E. to IR 770	16,780	0.37	6,209	9,996
	OLD US 36 to SR 267	23,220	1.48	34,366	55,329
	SR 267 to Marion County line	29,030	3.82	110,895	178,540
	Hend. Co. line to Country Club Rd.	32,580	1.01	32,906	52,978
	Country Club Rd. to Eleanor St.	35,830	1.42	50,879	81,915
	Eleanor St. to I-465	32,210	0.73	23,513	37,856
	US 36 TOTAL		39.74	453,657	730,388

Table B.2: Cloverdale Volume Calculations 2

Cloverdale Sub-district					
Road	Segment Description	ADT	Length Mile	Volume Mile/Day	Volume Km/Day
US 40	Clay County line to IR 27	5,270	4.67	24,611	39,624
	425 West to SR 243	4,090	3.56	14,560	23,442
	SR 243 to US 231	4,840	2.54	12,294	19,793
	US 231 to SR 75	4,890	8.51	41,614	66,998
	SR 75 to Hendricks County line	5,270	0.42	2,213	3,564
	Putnam County line to IR 33	6,360	7.90	50,244	80,893
	00 E/W to SR 39	9,330	1.96	18,287	29,442
	SR 39 to IR 57	10,060	1.78	17,907	28,830
	400 E. to IR 489	10,960	2.15	23,564	37,938
	600 E. to IR 165	11,970	0.45	5,387	8,672
	Vestal Rd. to SR 267	17,940	0.70	12,558	20,218
	SR 267 to Holiday Dr.	20,560	1.06	21,794	35,088
	Holiday Dr. to SR 267	30,550	0.33	10,082	16,231
	SR 267 to IR 79	39,460	0.79	31,173	50,189
	900 E. to Marion County line	21,240	2.09	44,392	71,470
	US 40 TOTAL		38.91	330,678	532,392
US 231	SR 46 to SR 67	7,260	5.33	38,696	62,300
	SR 67 to Putnam County line	3,130	8.64	27,043	43,540
	Owen County line to IR 4	4,470	1.05	4,694	7,557
	1200 South to SR 42	5,280	1.03	5,438	8,756
	SR 42 to Logan St.	6,930	0.75	5,198	8,368
	Logan St. to IR 122	9,360	1.45	13,572	21,851
	900 South to I-70	17,490	0.24	4,198	6,758
	I-70 to US 40	10,010	3.66	36,637	58,985
	US 40 to Martinsville St.	9,750	3.89	37,928	61,063
	Martinsville St. to Seminary St.	13,680	0.63	8,618	13,876
	Seminary St. to SR 240	13,840	0.17	2,353	3,788
	SR 240 to Indiana St.	17,110	0.28	4,791	7,713
	Indiana St. to Jackson St.	11,210	0.05	561	902
	Jackson St. to Liberty St.	17,020	0.15	2,553	4,110
	Liberty St. to IR 108	9,680	1.01	9,777	15,741
	Rangeline to IR 36	5,630	5.09	28,657	46,137
	500 North to US 36	4,000	2.27	9,080	14,619
	US 36 to SR 236 West	3,240	5.59	18,112	29,160
	SR 236 West to SR 236 East	3,210	0.50	1,605	2,584
	SR 236 to Montgomery County line	3,240	1.13	3,661	5,895
	US 231 TOTAL		42.91	263,169	423,702

Table B.3: Cloverdale Volume Calculations 3

Cloverdale Sub-district					
Road	Segment Description	ADT		Volume Mile/Day	Volume Km/Day
SR 39	Morgan Count line to I-70	4,750	0.89	4,228	6,806
	I-70 to US 40	3,110	4.45	13,840	22,282
	US 40 to Iowa St.	1,990	2.20	4,378	7,049
	Iowa St. to IR 20	2,250	0.90	2,025	3,260
	400 S. to Lincoln St.	1,200	3.79	4,548	7,322
	Lincoln St. to US 36	2,990	0.59	1,764	2,840
	SR 67 to SR 142	2,420	5.47	13,237	21,312
	SR 142 to IR 208	1,140	4.29	4,893	7,878
	IR 208 to SR 42 West	3,860	1.26	4,864	7,830
	SR 42 West to SR 42 East	6,610	0.02	132	213
	SR 42 East to IR 430	5,160	0.23	1,187	1,911
	IR 430 to Hendricks County line	4,600	1.27	5,842	9,406
	SR 39 TOTAL		25.36	60,937	98,109
SR 42	IR 223 to Owen County Line	570	3.19	1,818	2,927
	Clay County line to IR 225	510	1.28	653	1,051
	IR 225 to IR 292	660	1.37	904	1,456
	IR 292 to IR 219	1,040	1.71	1,778	2,863
	IR 219 to SR 243	1,450	1.47	2,132	3,432
	SR 243 to Putnum County line	1,360	1.26	1,714	2,759
	Owen County line to US 231	1,610	4.33	6,971	11,224
	US 231 to IR 129	940	1.99	1,871	3,012
	550 East to Morgan County line	520	3.75	1,950	3,140
	Putnam County line to IR 75	530	2.42	1,283	2,065
	UR 75 to SR 142	1,220	1.49	1,818	2,927
	SR 142 to IR 26	1,800	1.01	1,818	2,927
	IR 26 to IR 77	1,350	2.99	4,037	6,499
	IR 77 to IR 157	470	6.71	3,154	5,077
	IR 157 to IR 25	1,810	1.98	3,584	5,770
	IR 25 to SR 39	3,730	0.25	933	1,501
	SR 39 to IR 216	2,920	4.64	13,549	21,814
	IR 216 to SR 267	7,670	1.78	13,653	21,981
	SR 267 to Mooresville	14,990	0.50	7,495	12,067
	Moorseville to SR 42	22,080	0.11	2,429	3,910
	SR 42 TOTAL		44.23	53,750	86,538
SR 75	US 40 to Hendricks County line	1,670	0.18	301	484
	Putnam County line to IR 5	1,830	3.17	5,801	9,340
	Mastin Rd. to US 36	1,670	6.12	10,220	16,455
	US 36 to SR 236	640	7.50	4,800	7,728
	SR 75 TOTAL		16.97	21,122	34,007
SR 142	SR 142 to IR 25	840	8.34	7,006	11,279
	IR 25 to SR 39	1,560	1.82	2,839	4,571
	SR 142 TOTAL		10.16	9,845	15,850

Table B.4: Cloverdale Volume Calculations 4

Cloverdale Sub-district					
Road	Segment Description	ADT		Volume Mile/Day	Volume Km/Day
SR 144	SR 42 to IR 486	8,120	0.11	893	1,438
	IR 486 to SR 67	10,550	0.20	2,110	3,397
	SR 67 to IR 267	10,480	0.32	3,354	5,399
	SR 144TOTAL		0.63	6,357	10,234
SR 236	SR 59 to Putnam County line	370	2.24	829	1,334
	Parke County line to IR 379	490	1.64	804	1,294
	725 West to US 231	810	4.48	3,629	5,842
	US 231 to Indiana St.	1,190	5.41	6,438	10,365
	Indiana St. to Main St.	2,950	0.26	767	1,235
	Main St. to IR 67	1,430	1.44	2,059	3,315
	450 East to Hendricks County line	980	4.41	4,322	6,958
	Putnam County line to IR198	960	1.96	1,882	3,029
	IR 198 to SR 75	2,090	0.75	1,568	2,524
	SR 236 TOTAL		22.59	22,296	35,897
SR 240	US 231 to 1st St.	14,910	0.99	14,761	23,765
	1st St. to 10th St.	16,180	0.50	8,090	13,025
	10th St. to IR 63	13,760	1.75	24,080	38,769
	250 East to IR 189	4,030	2.06	8,302	13,366
	500 East to Hendricks County line	1,920	4.06	7,795	12,550
	Putnam County line to SR 75	2,450	0.89	2,181	3,511
	SR 240 TOTAL		10.25	65,208	104,986
SR 243	SR 42 to IR 386	520	0.50	260	419
	IR 386 to Putnam County line	470	0.88	414	666
	Owen County line to IR 92	840	2.65	2,226	3,584
	1050 South to I-70	1,170	1.43	1,673	2,694
	I-70 to US 40	620	4.01	2,486	4,003
	SR 243 TOTAL		9.47	7,059	11,365
SR 267	Morgan County line to IR 461	4,910	1.63	8,003	12,885
	750 E. to IR 90	4,050	0.74	2,997	4,825
	700 S. to I-70	11,610	1.06	12,307	19,814
	I-70 to US 40	17,670	4.37	77,218	124,321
	US 40 to IR 34	7,230	3.01	21,762	35,037
	100 S. to US 36	7,390	1.01	7,464	12,017
	SR 267 TOTAL		11.82	129,751	208,899

Table B.5: Cloverdale Volume Totals by Road

Cloverdale Sub-district				
Road ALL	Segment Description	Length Mile	Volume Mile/Day	Volume Km/Day
	I-70 TOTAL	42.01	1,239,828	1,996,123
	US 36 TOTAL	39.74	453,657	730,388
	US 40 TOTAL	38.91	330,678	532,392
	US 231 TOTAL	42.91	263,169	423,702
	SR 39 TOTAL	25.36	60,937	98,109
	SR 42 TOTAL	44.23	53,750	86,538
	SR 75 TOTAL	16.97	21,122	34,007
	SR 142 TOTAL	10.16	9,845	15,850
	SR 144TOTAL	0.63	6,357	10,234
	SR 236 TOTAL	22.59	22,296	35,897
	SR 240 TOTAL	10.25	65,208	104,986
	SR 243 TOTAL	9.47	7,059	11,365
	SR 267 TOTAL	11.82	129,751	208,899
	TOTAL	315.05	2,663,658	4,288,489

Table B.6: Cloverdale Volume Total

Cloverdale Sub-district				
Road ALL	Segment Description	Length Mile	Volume Mile/Day	Volume Km/Day
	Two lane Highway	153.96	709,329	1,142,000
	Four lane Highway	161.09	1,954,329	3,146,000
	TOTAL	315.05	2,663,658	4,288,000

Table B.7: Plymouth Volume Calculations 1

Plymouth Sub-district					
Road	Segment Description	ADT	Length Mile	Volume Mile/Day	Volume Km/Day
US 6	Laport County line to SR 104	3,810	1.62	6,172	9,937
	SR 104 to Washington St.	4,540	0.36	1,634	2,631
	Washington St. to SR 23	7,210	0.32	2,307	3,715
	SR 23 to Georgia St.	6,980	0.27	1,885	3,034
	Georgia St. to Marshall County line	4,230	0.99	4,188	6,742
	St. Joe County line to IR 37	4,730	7.33	34,671	55,820
	North Oak Road to US 31	5,510	0.94	5,179	8,339
	US 31 to IR 289	9,110	1.25	11,388	18,334
	North Lilac Rd. to SR 106	9,530	4.16	39,645	63,828
	SR 106 to SR 331	7,660	2.88	22,061	35,518
	SR 331 to SR 106	8,170	1.26	10,294	16,574
	SR 106 to IR 331	11,120	1.83	20,350	32,763
	Pl-G Trl. to Elkhart Co. line	9,390	2.21	20,752	33,411
	Marshall County line to IR 85	8,480	1.51	12,805	20,616
	IR 85 to SR 19	13,710	1.52	20,839	33,551
	US 6 TOTAL		28.45	214,169	344,812
US 20	Laporte County line to CR 349	6,790	1.39	9,438	15,195
	CR 349 to Quince Rd.	6,140	6.31	38,743	62,377
	Quince Rd. to Pine Rd.	7,230	1.61	11,640	18,741
	Pine Rd. to US 31	8,460	0.67	5,668	9,126
	US 31 to Mayflower Rd.	12,220	4.03	49,247	79,287
	Mayflower Rd. to Sheridan Ave.	16,440	1.52	24,989	40,232
	Sheridan Ave. to US 31	22,000	2.75	60,500	97,405
	US 31 to Ironwood Dr.	11,566	1.89	21,860	35,194
	Ironwood Dr. to US 331	28,150	2.03	57,144	92,003
	US 331 to Elkhart County line	16,077	6.10	98,068	157,889
	US 20 TOTAL		28.30	377,297	607,449
US 30	SR 23 to Marshall County line	11,200	2.14	23,968	38,588
	Starke County line to SR 17	15,450	8.18	126,381	203,473
	SR 17 to IR 232	14,380	0.91	13,086	21,068
	P-G Trl. to US 31	14,160	0.96	13,594	21,886
	US 31 to IR 49	12,800	1.04	13,312	21,432
	East 9A to IR 57	14,750	2.35	34,663	55,807
	South Iris Rd. to SR 331	12,800	5.63	72,064	116,023
	SR 331 to Kosciusko County line	13,220	3.68	48,650	78,326
	Kosciuosko County line to SR 19	10,820	0.58	6,276	10,104
	US 30 TOTAL		25.47	351,992	566,707

Table B.8: Plymouth Volume Calculations 2

Plymouth Sub-district					
Road	Segment Description	ADT	Length Mile	Volume Mile/Day	Volume Km/Day
US 31	Marshall County line to Lake Trail	17,760	3.41	60,562	97,504
	Lake Trail to Jefferson St.	18,830	0.64	12,051	19,402
	Jefferson St. to SR 4	24,180	0.41	9,914	15,961
	SR 4 to CR 26	23,700	1.03	24,411	39,302
	Osbourne Rd. to CR46	18,180	3.14	57,085	91,907
	Roosevelt Td. to US 31 bypass	23,180	2.11	48,910	78,745
	US 31 bypass to SR 20	11,540	8.30	95,782	154,209
	US 20 to I-80/I-90	14,010	1.69	23,677	38,120
	I-80/I-90 to Michigan State line	11,670	2.63	30,692	49,414
	SR 10 to Old US 31	12,450	3.51	43,700	70,356
	Old US 31 to IR 373	14,300	0.81	11,583	18,649
	Michigan Rd. to US 30	12,990	3.44	44,686	71,944
	US 30 to IR 375	12,690	6.29	79,820	128,510
	Michigan Rd. to US 6	20,640	1.16	23,942	38,547
	US 6 to St. Joe County line	17,240	1.93	33,273	53,570
	US 31 TOTAL		40.50	600,087	966,141
US 33	Elkhart County line to Vistula Rd.	15,460	3.36	51,946	83,632
	Vistula Rd. to Byrkit Rd.	22,250	1.69	37,603	60,540
	Byrkit Rd. to SR 331	16,310	1.21	19,735	31,774
	Main St. to Ironwood Dr.	16,620	1.86	30,913	49,770
	Ironwood Dr. to Twyckenham Dr.	19,350	0.54	10,449	16,823
	Twyckenham Dr. to Miami St.	18,750	0.55	10,313	16,603
	Miama St. to SR23	26,260	0.23	6,040	9,724
	SR 23 to Michigan St.	21,890	0.68	14,885	23,965
	Michigan St. to Western Ave.	14,250	0.49	6,983	11,242
	Western Ave. US 20	20,860	0.38	7,927	12,762
	US 20 to US 33 SB	17,130	0.31	5,310	8,550
	US 20 to US 33 NB	16,680	0.31	5,171	8,325
	US 20 to Monroe St.	20,360	0.46	9,366	15,079
	Monroe St. to SR 23	15,400	0.49	7,546	12,149
	SR 23 to US 33	22,480	0.11	2,473	3,981
	SR 33 to Riverside Do.	26,500	0.33	8,745	14,079
	Riverside Dr. to I-80/I-90	23,950	2.47	59,157	95,242
	I-80/I-90 to Darden Rd.	29,070	0.54	15,698	25,273
	Darden Rd. to Michigan State line	20,110	2.09	42,030	67,668
	US 33 TOTAL		18.10	352,287	567,182

Table B.9: Plymouth Volume Calculations 3

Plymouth Sub-district						
Road	Segment Description	ADT	Length Mile	Volume Mile/Day	Volume Km/Day
SR 2	LaPorte County line to IR 177	12,990	7.39	95,996	154,554
	IR 177 to IR 87	14,750	1.62	23,895	38,471
	IR 87 to US 31	16,400	0.59	9,676	15,578
	US 31 to Mayflower Rd.	10,770	0.98	10,555	16,993
	SR 2 TOTAL		10.58	140,122	225,596
SR 4	SR 23 to Lafayette St.	2,430	0.09	219	352
	Lafayette St. to IR 9	1,780	1.91	3,400	5,474
	IR 9 to IR 17	2,160	2.96	6,394	10,294
	IR 17 to US 31	2,150	3.05	6,558	10,558
	SR 4 TOTAL		8.01	16,570	26,677
SR 8	Starke County line to SR 17	1,790	2.70	4,833	7,781
	US 35 to East St.	5,240	2.13	11,161	17,970
	East St. to IR 55	3,710	1.37	5,083	8,183
	IR 55 to SR 23	2,730	3.50	9,555	15,384
	SR 23 to Marshall County line	2,170	3.01	6,532	10,516
	SR 8 TOTAL		12.71	37,164	59,833
SR 17	SR 10 to SR 8	2,900	5.24	15,196	24,466
	SR 8 to IR 44	3,250	1.35	4,388	7,064
	West 12th Rd. to IR 189	3,770	4.04	15,231	24,522
	South Quince Rd. to IR 29	5,380	1.66	8,931	14,379
	South Olive Trl. to North Oak Rd.	8,240	0.65	5,356	8,623
	North Oak Rd. to Michigan St.	7,530	1.10	8,283	13,336
	Michigan St. to Jefferson St.	11,780	0.26	3,063	4,931
	Jefferson St. to US 30	16,690	1.28	21,363	34,395
	SR 17 TOTAL		15.58	81,810	131,714

Table B.10: Plymouth Volume Calculations 4

Plymouth Sub-district					
Road	Segment Description	ADT	Length Mile	Volume Mile/Day	Volume Km/Day
SR 23	Starke County line to Virginia Sr.	3,410	2.07	7,059	11,365
	Virginia St. to Indiana St.	5,160	0.20	1,032	1,662
	Indiana St. to SR 23	3,380	0.34	1,149	1,850
	SR 23 to IR 2	6,400	0.85	5,440	8,758
	IR 2 to Maple St.	5,010	4.83	24,198	38,959
	Maple St. to SR 4	5,300	0.33	1,749	2,816
	SR 4 to Mill St.	7,040	0.27	1,901	3,060
	Mill St. to IR 145	5,270	2.92	15,388	24,775
	IR 145 to IR 117	7,350	0.89	6,542	10,532
	IR 117 to IR 15	4,870	4.45	21,672	34,891
	IR 15 to IR 17	7,780	1.16	9,025	14,530
	IR 17 to IR 60	7,940	0.08	635	1,023
	IR 60 to US 31	4,660	1.47	6,850	11,029
	US 31 to Olive St.	8,240	0.94	7,746	12,470
	Olive St. to Indiana St.	5,240	1.08	5,659	9,111
	Indiana St. to Sample St.	8,520	0.57	4,856	7,819
	Sample St. to US 33	20,840	0.48	10,003	16,105
	US 33 to Jefferson Blvd.	23,650	1.38	32,637	52,546
	Jefferson Blvd. to US 20	21,450	0.19	4,076	6,562
	US 20 to Madison St.	16,210	0.19	3,080	4,959
	Madison St. to South Bend Ave.	14,290	0.46	6,573	10,583
	South Bend Ave. Twyckenham Dr.	13,170	0.62	8,165	13,146
	Twyckenham Dr. to IR 97	16,260	0.68	11,057	17,801
	IR 97 to IR 101	23,890	1.59	37,985	61,156
	IR 101 to Grape Rd.	14,010	0.70	9,807	15,789
	Grape Rd. to IR 86	16,310	0.63	10,275	16,543
	IR 86 to IR105	13,370	3.95	52,812	85,027
	IR 105 to IR 202	10,380	1.04	10,795	17,380
	IR 202 to Michigan State line	7,260	0.54	3,920	6,312
	SR 23 to IR 30	610	2.02	1,232	1,984
	IR 30 to SR 8	1,140	2.02	2,303	3,708
	SR 8 to IR 52	1,110	2.51	2,786	4,486
	IR 52 to SR 23	1,020	1.47	1,499	2,414
	SR 23 to IR 470	370	2.80	1,036	1,668
	IR 470 to US 30	1,690	0.06	101	163
	US 30 to IR 198	2,940	1.30	3,822	6,153
	IR 198 to SR 23	1,840	2.28	4,195	6,754
	SR 23 to St. Joe County line	3,230	1.56	5,039	8,112
	SR 23 TOTAL		50.92	344,100	554,002

Table B.11: Plymouth Volume Calculations 5

Road	Segment Description	ADT	Length Mile	Volume Mile/Day	Volume Km/Day
Plymouth Sub-district					
SR 106	US 6 to IR 63	2,110	1.72	3,629	5,843
	Goshen Trl. to Liberty Dr.	5,060	0.72	3,643	5,866
	Liberty Dr. to SR 331	9,870	0.24	2,369	3,814
	SR 331 to Center St.	9,120	0.51	4,651	7,488
	Center St. to SR 331	5,800	0.42	2,436	3,922
	SR 331 US 6	2,970	0.72	2,138	3,443
	SR 106 TOTAL		4.33	18,867	30,376
SR 331	SR 10 to IR 188	2,030	2.97	6,029	9,707
	13th Trl Rd. to Center St.	3,930	0.51	2,004	3,227
	Center St. to Jefferson St.	3,120	0.30	936	1,507
	Jefferson St. to US 30	2,470	0.87	2,149	3,460
	US 30 to IR 76	2,540	4.43	11,252	18,116
	East 7th Rd. to IR 94	2,100	3.50	7,350	11,834
	East 3B Rd. to IR 332	2,470	1.19	2,939	4,732
	East 2D Rd. to Hill Trl. Rd.	1,760	0.76	1,338	2,154
	Hill Trl. Rd. to SR 106	1,850	1.28	2,368	3,812
	SR 106 to US 6	5,260	0.94	4,944	7,960
	US 6 to IR 166	4,570	0.31	1,417	2,281
	East 1st Rd. to St. Joe County line	5,260	1.02	5,365	8,638
	Marshall County line to IR 20	4,950	3.28	16,236	26,140
	IR 20 to IR 158	5,440	5.36	29,158	46,945
	IR 158 to IR 58	6,630	1.49	9,879	15,905
	IR 58 to IR 276	8,040	0.50	4,020	6,472
	IR 276 to Union St.	10,050	1.45	14,573	23,462
	Union St. to US 33	12,410	0.89	11,045	17,782
	US 33 to Front St.	12,000	0.13	1,560	2,512
	Front St. to Jefferson Blvd.	23,640	0.70	16,548	26,642
	Jefferson Blvd. to SR 331	13,490	0.50	6,745	10,859
	SR 331 TOTAL		32.38	157,855	254,147

Table B.12: Plymouth Volume Totals by Road

Plymouth Sub-district				
Road ALL	Segment Description	Length Mile	Volume Mile/Day	Volume Km/Day
	US 6 TOTAL	28.45	214,169	344,812
	US 20 TOTAL	28.30	377,297	607,449
	US 30 TOTAL	25.47	351,992	566,707
	US 31 TOTAL	40.50	600,087	966,141
	US 33 TOTAL	18.10	352,287	567,182
	SR 2 TOTAL	10.58	140,122	225,596
	SR 4 TOTAL	8.01	16,570	26,677
	SR 8 TOTAL	12.71	37,164	59,833
	SR 17 TOTAL	15.58	81,810	131,714
	SR 23 TOTAL	50.92	344,100	554,002
	SR 106 TOTAL	4.33	18,867	30,376
	SR 331 TOTAL	32.38	157,855	254,147
	TOTAL	275.33	2,692,320	4,334,636

Table B.13: Plymouth Volume Total

Plymouth Sub-district				
Road ALL	Segment Description	Length Mile	Volume Mile/Day	Volume Km/Day
	Two lane Highway	176.96	1,319,450	1,926,000
	Four lane Highway	98.37	1,372,870	2,409,000
	TOTAL	275.33	2,692,320	4,335,000

Table B.14: Tipton Volume Calculations 1

Tipton Sub-district					
Road	Segment Description	ADT	Length Mile	Volume Mile/Day	Volume Km/Day
US 31	I 465 to 116th St.	39,270	1.78	69,901	112,540
	116th St. to 131st St.	32,830	1.50	49,245	79,284
	131st St. to Rangeline Rd.	23,780	1.94	46,133	74,274
	Rangeline Rd. to SR 431	27,180	0.44	11,959	19,254
	SR 431 to 146th St.	47,820	0.34	16,259	26,177
	146th St. to 169th St.	32,030	2.06	65,982	106,231
	169th St. to SR 32	38,090	0.70	26,663	42,927
	SR 32 to 196th St.	28,600	3.61	103,246	166,226
	196th St. to SR 38	26,260	2.53	66,438	106,965
	SR 38 to 236th St.	23,150	5.90	136,585	219,902
	236th St. to Hamilton County line	23,340	5.90	137,706	221,707
	Tipton County line to SR 28	20,840	4.03	83,985	135,216
	SR 28 to Howard County line	21,210	8.85	187,709	302,211
	Howard County line to SR 26	24,150	1.01	24,392	39,270
	SR 26 to Lafountain St.	27,830	1.34	37,292	60,040
	Lafountain St. to Lincoln Rd.	31,410	1.45	45,545	73,327
	Lincoln St. to Sycamore St.	33,305	2.42	80,598	129,763
	Sycamore St. to North St.	26,050	0.61	15,891	25,584
	North St. to US 35	24,250	3.12	75,660	121,813
	US 35 to Miami County line	18,460	1.48	27,321	43,986
	US 31 TOTAL		51.01	1,308,508	2,106,697
US 35	Cass County line to US 31	6,920	3.43	23,736	38,214
	US 31 to 200 E.	15,220	5.58	84,928	136,733
	200 E. to 300 E.	12,690	1.02	12,944	20,840
	300 E. to SR 19	9,980	2.00	19,960	32,136
	SR 19 to Meridian Sr.	9,690	3.44	33,334	53,667
	Meridian St. to SR 213	8,060	0.50	4,030	6,488
	SR 213 to 1000 E.	6,210	1.00	6,210	9,998
	1000 E. to Grant County line	4,560	3.96	18,058	29,073
	US 35 TOTAL		20.93	203,198	327,149

Table B.15: Tipton Volume Calculations 2

Tipton Sub-district					
Road	Segment Description	ADT	Length Mile	Volume Mile/Day	Volume Km/Day
SR 13	SR 37 to south P	6,930	0.96	6,653	10,711
	South P to SR 28	17,640	0.99	17,464	28,116
	SR 28 to North F	11,800	0.39	4,602	7,409
	North F to 1300 N.	6,430	0.63	4,051	6,522
	1300 N. to 1500 N.	2,700	1.99	5,373	8,651
	1500 N. to Grant County Line	1,930	4.00	7,720	12,429
	SR 13 TOTAL		8.96	45,862	73,838
SR 19	SR 32 to Logan st.	9,090	0.10	909	1,463
	Logan St. to Buckeye St.	9,640	5.84	56,298	90,639
	Buckeye St. to Jackson St.	11,590	0.11	1,275	2,053
	Jackson St. to 241st St.	10,770	0.52	5,600	9,017
	241st St. to Main St.	8,410	2.46	20,689	33,309
	Main St. to Central St.	5,410	2.26	12,227	19,685
	Central St. to Tipton County line	4,030	1.03	4,151	6,683
	Tipton County line to 400 S.	4,800	2.11	10,128	16,306
	400 S. to 300 S.	4,950	1.01	5,000	8,049
	300 S. to SR 28	5,780	1.45	8,381	13,493
	SR 28 to East St.	11,950	0.17	2,032	3,271
	East St. to SR 28	12,610	0.34	4,287	6,903
	SR 28 to North St.	7,980	0.26	2,075	3,340
	North St. to Hill St.	4,240	0.55	2,332	3,755
	Hill St. to Divison Rd.	3,640	0.64	2,330	3,751
	Division Rd. to 600 N.	3,310	5.97	19,761	31,815
	600 N. to Howard County line	3,260	0.99	3,227	5,196
	Tipton County line to SR 26	3,210	1.01	3,242	5,220
	SR 26 to 300 S.	4,860	1.00	4,860	7,825
	300 S. to 100 S.	3,860	2.01	7,759	12,491
	100 S. to SR 22	2,930	0.79	2,315	3,727
	SR 19 TOTAL		30.62	178,875	287,989
SR 22	Carroll Country line to 1150 W.	3,250	1.47	4,778	7,692
	1150 W. to 750 W.	3,860	4.03	15,556	25,045
	750 W. to 600 W.	4,710	1.50	7,065	11,375
	600 W. to 400 W.	7,440	2.11	15,698	25,274
	400 W. to Dixon Rd.	11,155	2.02	22,533	36,278
	Dixon Rd. to Berkley St.	12,390	0.50	6,195	9,974
	Berkley St. to McCann St.	7,630	0.71	5,417	8,722
	McCann St. to Washington St.	7,150	0.43	3,075	4,950
	Washington St. to Park Ave.	17,570	0.19	3,338	5,375
	Park Ave. to Diamond St.	13,550	1.37	18,564	29,887
	Diamond St. to US 31	16,190	0.48	7,771	12,512
	SR 22 TOTAL		14.81	109,990	177,083

Table B.16: Tipton Volume Calculations 3

Tipton Sub-district					
Road	Segment Description	ADT	Length Mile	Volume Mile/Day	Volume Km/Day
SR 26	Clinton County line to 750 W.	3,370	1.96	6,605	10,634
	750 W. to Yale Blvd.	5,760	7.40	42,624	68,625
	Yale Blvd. to US 31	6,700	0.19	1,273	2,050
	US 31 to 200 E.	4,100	2.02	8,282	13,334
	200 E. to SR 19	3,500	3.03	10,605	17,074
	SR 19 ro SR 213	3,730	3.96	14,771	23,781
	SR 213 to Grant County line	2,780	4.97	13,817	22,245
	SR 26 TOTAL		23.53	97,977	157,742
SR 28	Clinton County line to 1150 W.	1,780	0.58	1,032	1,662
	1150 W. to 900 W.	2,400	2.50	6,000	9,660
	900 W. to US 31	2,490	3.06	7,619	12,267
	US 31 to Sweetland Ave.	5,320	4.23	22,504	36,231
	Sweetland Ave. to Main St.	7,610	0.44	3,348	5,391
	Main St. to 25 W.	7,230	1.14	8,242	13,270
	25 W. to SR 213	6,030	3.31	19,959	32,134
	SR 213 to 800 E.	4,890	4.13	20,196	32,515
	800 E. to 9th St.	5,370	1.55	8,324	13,401
	9th St. to SR 13	10,190	0.44	4,484	7,219
	SR 13 to 800 W.	19,230	1.35	25,961	41,796
	800 W. to SR 37	10,620	0.37	3,929	6,326
	SR 28 TOTAL		23.10	131,598	211,873
SR 32	Boone County line to Joliet Rd.	4,430	0.53	2,348	3,780
	Joliet Rd. to Spring Mill Rd.	4,880	3.51	17,129	27,577
	Spring Mill Rd. to US 31	8,170	1.60	13,072	21,046
	US 31 to Little Chicago Rd.	13,180	3.41	44,944	72,360
	Little Chicago Rd. to SR 38	18,150	2.53	45,920	73,930
	SR 38 to SR 19	16,700	0.32	5,344	8,604
	SR 19 to 8th St.	17,060	0.24	4,094	6,592
	8th St. to 10th ST.	17,060	0.13	2,218	3,571
	10th St. to SR 37	16,300	0.96	15,648	25,193
	SR 32 TOTAL		13.23	150,716	242,653
SR 37	I 69 to SR 238	31,110	7.01	218,081	351,111
	SR 238 to SR 32	24,430	1.61	39,332	63,325
	SR 32 to 186th St.	14,870	1.40	20,818	33,517
	186th St. to Strawtown Ave.	12,340	4.94	60,960	98,145
	Strawtown Ave. to SR 213	8,330	0.45	3,748	6,035
	SR 213 to SR 13	6,650	11.21	74,547	120,020
	SR 37 TOTAL		26.62	417,486	672,152

Table B.17: Tipton Volume Calculations 4

Tipton Sub-district					
Road	Segment Description	ADT	Length Mile	Volume Mile/Day	Volume Km/Day
SR 38	Boone County line to 2nd St.	770	1.32	1,016	1,636
	2nd St. to Main St.	3,230	0.24	775	1,248
	Main St. to 3rd St.	6,980	0.06	419	674
	3rd St. to Main St.	6,690	0.19	1,271	2,046
	Main St. to White St.	3,090	0.30	927	1,492
	White St. to SR 47	4,950	0.32	1,584	2,550
	SR 47 to US 31	5,360	5.03	26,961	43,407
	US 31 to Little Chicago Rd.	4,860	3.44	16,718	26,917
	Little Chicago Rd. to SR 32	12,235	5.69	69,617	112,084
	SR 38 TOTAL		16.59	119,289	192,055
SR 213	SR 37 to 266 th St.	1,490	3.25	4,843	7,796
	266th St. to Tipton County line	1,010	2.90	2,929	4,716
	Hamilton County line to SR 28	1,370	5.55	7,604	12,242
	SR 28 to 100 N.	1,970	2.36	4,649	7,485
	100 N. to S. Park St.	2,390	2.57	6,142	9,889
	S. Park St. to Sherman St.	2,810	0.39	1,096	1,764
	Sherman St. to 500 N.	2,480	1.00	2,480	3,993
	500 N. to 600 N.	2,110	0.99	2,089	3,363
	600 N to Howard County line	1,740	1.04	1,810	2,913
	Tipton County line to SR 26	1,540	0.98	1,509	2,430
	SR 26 to 200 S.	1,130	2.00	2,260	3,639
	200 S. to Lincoln St.	1,860	1.80	3,348	5,390
	Lincoln St. US 35/ SR22	2,240	0.13	291	469
	SR 213 TOTAL		24.96	41,049	66,089
SR 431	SR 37 to 266 th St.	33,520	2.00	67,040	107,934
	266th St. to Tipton County line	26,150	1.50	39,225	63,152
	Lincoln St. US 35/ SR22	7,890	1.78	14,044	22,611
	SR 431 TOTAL		5.28	120,309	193,698

Table B.18: Tipton Volume Totals by Road

Tipton Sub-district				
Road ALL	Segment Description	Length Mile	Volume Mile/Day	Volume Km/Day
	SR 13 TOTAL	8.96	45,862	73,838
	SR 19 TOTAL	30.62	178,875	287,989
	SR 22 TOTAL	14.81	109,990	177,083
	SR 26 TOTAL	23.53	97,977	157,742
	SR 28 TOTAL	23.10	131,598	211,873
	US 31 TOTAL	51.01	1,308,508	2,106,697
	SR 32 TOTAL	13.23	150,716	242,653
	US 35 TOTAL	20.93	203,198	327,149
	SR 37 TOTAL	26.62	417,486	672,152
	SR 38 TOTAL	16.59	119,289	192,055
	SR 213 TOTAL	24.96	41,049	66,089
	SR 431 TOTAL	5.28	120,309	193,698
	TOTAL	259.64	2,924,857	4,709,020

Table B.19: Tipton Volume Total

Tipton Sub-district				
Road ALL	Segment Description	Length Mile	Volume Mile/Day	Volume Km/Day
	Two lane Highway	193.33	1,217,809	1,961,000
	Four lane Highway	66.31	1,707,048	2,748,000
	TOTAL	259.64	2,924,857	4,709,000

APPENDIX C

Figure 1. Fuel consumption rates of a passenger car for various ice and snow conditions.

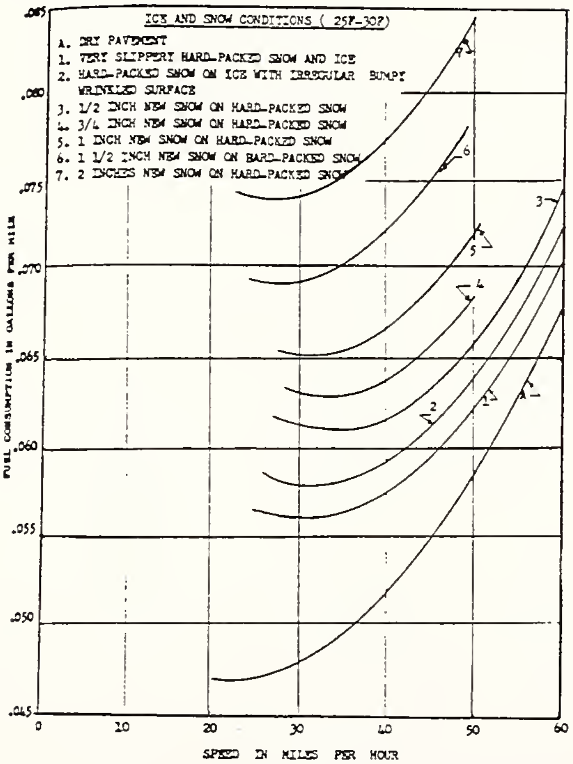

Figure C.1: Claffey Curves

APPENDIX D

Table D.1: Initial Hardware Investment for RPUs

Item	Unit Price	Number	Total Price	Remarks
Remote Processing Unit RPU software license 1200 buad modem NEMA aluminum enclosure	12,648	37	467,976	RPU processes and stores field data until it is transferred
Tower, 10 foot base	885	37	32,745	Contains base & non-climbable shields
Tower, 10 foot mid	868	37	32,116	Foldover mechanism
Tower, 10 foot top	260	37	9,620	
Weather identifier sensor package; temperature, relative humidity, visibility and weather identifier	11,603	37	429,311	WIVIS identifies precipitation type, rate, daily accumulation and visibility
Wind speed and direction sensor	586	37	21,682	
Freeze point surface sensor, model FP2000	2,873	148	425,204	Four sensors per RPU
Subsurface temperature probe	892	37	33,004	Placed below one of the surface sensors
Splice kit without tools	35	185	6,475	Five kits per RPU
Subsurface and surface extension cable	0.55	38,850	21,368	Five cables, avg. length 210 ft.
MAP graphic software license	1,014	37	37,518	Map for graphic display of RWIS data
Radio Communications to CPU	4,485	37	165,945	Data transmission between RPU and CPU
Commissioning	1,890	37	69,930	Final setup, calibration and system evaluation
Total RPU equipment	47,376	37	1,752,894	

Table D.2: Initial Installation Investment for RPUs

Item	Unit Price	Number	Total Price	Remarks
RPU site installation RPU Tower Atmospheric sensors Chain link fence 2 surface sensors on bridge deck 2 surface sensors on approach 1 subsurface sensor 500' trenching 200' conduit on bridge deck 100' trenching & install power	27,100	37	1,002,700	Installation includes the specified trenching, placement of conduit; connection of cables, and power; installation of all sensors; erection of a protective fence, and site landscaping
Total RPU install	27,100	37	1,002,700	

Table D.3: Initial Hardware Investment for CPUs

Item	Unit Price	Number	Total Price	Remarks
SCAN Plus CPU Intel processor I/O 8 port communications board IBM communications board Monochrome Monitor Scan Plus software license Uninterruptable Power Supply Commissioning	18,760	7	131,320	Scan Plus CPU collects data from all RPUs, receives forecasts from forecasting service
Total CPU equipment	18,760	7	131,320	

Table D.4: Initial Hardware and Services
for the Sub-districts

Item	Unit Price	Number	Total Price	Remarks
SCAN Color graphics software license	347	37	12,839	PCs at the 37 sub-districts
486 Computer	3,000	37	111,000	State software
Laptop PC	4,300	37	159,100	State software
Total for sub-district equipment and services	7,647	37	282,939	

Table D.5: Total Initial Hardware
and Services Investment

Item	Price
Hardware for (RPU)s	1,752,894
Installation for (RPU)s	1,002,700
Hardware for (CPU)s	131,320
Hardware and services for the sub-districts	282,939
Total initial investment	3,169,853

Table D.6: Year 1 Operational Costs

Item	Unit Price	Number	Total Price	Remarks
Radio communications RPU to CPU	935	37	34,595	service of radio equipement
Communications user to CPU	18.60	37	688	Estimated average cost to dial into CPU
Weather forecasting	1,740	37	64,380	Forecasts for 50 sites for 6 months
Training	8,200 per week	6	49,200	30 days fo training (intro to RWIS, RWIS tools, Using RWIS, Advanced RWIS, RWIS Maintenance & Annual Appraisal
Service/ Maintenance RPUs	0	37	0	Under Waranty
Total first year operational costs	3,088	37	114,268	

Table D.7: Additional Year Operational Costs

Item	Unit Price	Number	Total Price	Remarks
Radio communications maintenance (RPU to CPU)	935	37	34,595	service of radio equipement
Communications user to CPU	18.60	37	688	Estimated average cost to dial into CPU
Weather forecasting	1,740	37	64,380	Forecasts for 37 sites for 6 months
Training	8,200 per week	2	16,400	10 Days of training (Advanced RWIS & Annual RWIS Appraisal)
Service / Maintenance RPUs	3,000	37	111,000	Service for 37 RPUs
Total additional year operational costs	5,202	37	192,468	

Table D.8: Year 1 Total Costs

Item	Price
Hardware for (RPU)s	1,752,894
Installation for (RPU)s	1,002,700
Hardware for (CPU)s	131,320
Hardware and services for the sub-districts	282,939
Operational Costs	114,268
Total Year 1 Costs	3,284,121

Table D.9: Additional Year Costs

Item	Price
Operational Costs	192,468
Total additional year costs	192,468

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